The Technological Context of Crucible Steel Production in Northern Telangana, India.

Volume 1 of 2

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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Abstract

The innovation of crucible steel, a high-carbon, homogeneous, slag-free steel, is regarded as a milestone in the history of the development of ferrous metallurgy. Associated in popular literature with the making of swords, particularly in the Early Islamic period, crucible steel, also known as wootz, possesses exceptional properties of hardness and strength. While much is now understood about its metallurgical composition and structure, little is known of its origins and spread. Few archaeological sites have been uncovered and to date pre-industrial production of this alloy is only known from Central Asia and South Asia. Previous studies have largely focused on individual sites in isolation from wider regional patterns of ferrous metallurgy. As a refining process of iron, it is argued here that crucible steel has a symbiotic relationship with the smelting technologies that produced the raw material for refining. This thesis explores the value of assessing crucible steel production within its wider landscape, cultural and technological context by presenting the evidence from Northern Telangana, India.

Historical sources and recent archaeological field surveys have shown that Telangana has a rich metallurgical past, including the manufacture of crucible steel. Despite this, little archaeological work has been conducted in the region to elucidate the nature, scale and diversity of the metallurgical technologies that underpinned its production. Following a major reconnaissance survey in 2010 by the Pioneering Metallurgy Project, the present study tackled the assessment of the large body of field data and the recording of the technological waste assemblage collected. By combining detailed morphological analyses of the collected materials and contextual information recorded during field survey, a better understanding of the techno-cultural role of crucible steel was gained.

Technological variations were identified across the survey area and the inter-relationship between iron smelting and crucible steel was assessed. The study reveals that crucible steel was embedded within a long-established local and regional tradition of iron smelting and concludes that it represented the intensification of a pre-existing iron processing industry. The evidence points to a widespread crucible steel production industry with varying degrees of site specialisation, indicating that it was perhaps more common than the few isolated sites commonly referred to in the literature suggests. The comparison of the material

evidence with other production sites in Central and South Asia also revealed close parallels to the latter suggesting that they belonged to the same regional manufacturing tradition.

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1 Introduction

The early development of high-carbon crucible steel technologies in South Asia is recognised as a milestone in the history of science and technology, due to the material's exceptional properties combining high strength, hardness and ductility. This is reflected in popular histories surrounding the making of swords across Asia and the Islamic world using this material. Not only has it given us the legends of the swords of Damascus, first encountered by the West in the time of the Crusades (Bronson 1986; Feuerbach 2006; Le Coze 2007; Hall 1991), but it also fed the acquisition of technological knowledge from newly conquered colonies by western scientists, industrialists and entrepreneurs. Indeed, it is argued that pioneering research on high-carbon Asian crucible steel and its distinctive properties during the 19th century gave birth to the modern discipline of material science (Srinivasan and Ranganathan 2004, 77-87; 2011). Michael Faraday, James Stodart, Henry Wilkinson and David Mushet were among those who recognised the nature of this material and sought to recreate it in Europe early in the Industrial Revolution (Balasubramaniam 2008, 235; Bronson 1986; Srinivasan and Ranganathan 2004, 81-3).

1.1 Iron and Steel

To understand the unique properties of crucible steel, it is important to first outline the main methods of past iron production (smelting). The most ancient method of manufacturing iron was by a solid state reduction of the iron oxide in iron bearing mineral ores, also known as the bloomery process. This was to an extent superseded by the blast furnace process as early as 5th century BCE in China (Craddock 2003, 237; Needham 1980; Wagner 1993) and as late as the 15th century AD in Europe (Craddock 2003, 249; Tylecote 1962, 300; 1992, 95). Both methods involve smelting iron ore along with fuel (typically charcoal) in a furnace; a structure generally made of clay in which this charge is held. The process is accelerated by the blowing of air (with bellows) into the furnace through purposely made openings, or tuyeres. The carbon monoxide produced by the burning charcoal reduces the iron oxide in the ore to metallic iron. This is possible at temperatures of about 800°C which is well below the melting point of iron, at 1540°C (Tylecote 1962, 183). However, iron ores not only consist of iron oxides but also contain many unwanted elemental compounds and minerals which have to be removed during smelting. These gangue minerals combined with iron oxide have a lower melting temperature than iron (about 1150°C) and can be removed by liquation as a slag (Tylecote 1962, 183). This is where bloomery and blast furnace smelting differs.

To produce iron by the bloomery process, temperatures have to be above 1150°C but below the melting point of iron (typically around 1200-1300°C) enabling the impurities in the ore to melt away while the semi-malleable iron coalesces (Craddock 1995, 244-6; Schrüfer-Kolb 2004, 7). The unwanted mineral components forms what is known as slag, the primary waste material of the iron smelting process (Tylecote 1962, 183). This method forms a spongey mass of low carbon (0-0.8%) iron and slag called a 'bloom' which gives the name to the process. The bloom can then be refined by smithing, which is the manipulation of iron by hammering (forging) the heated bloom between an anvil and a hammer (Bayley *et al* 2001; Craddock 1995, 247-9). Smithing is usually separated into two main phases; primary and secondary smithing. Primary smithing is the consolidation of the raw iron bloom (Bayley *et al* 2001; Crew 1996). The main objective here is to remove the largest proportion of slag which may be adhering to the surface or trapped within the iron. Secondary smithing is when the consolidated/refined iron is shaped to produce finished artefacts (Bayley *et al* 2001; Crew 1996).

The blast furnace process follows similar principles but the operating temperatures are higher, typically between 1300-1400°C, allowing iron to be produced in a liquid state (Craddock 2003, 234-5). This is achieved by increasing the air supply and fuel-to-ore ratio, forming a more reducing atmosphere. The reducing conditions produces a high-carbon iron (typically 2-5%) which lowers the melting point of the metal. This allows the iron to separate from the unwanted gangue minerals by sinking through the slag and accumulate at the base of the furnace as a liquid (Craddock 2003, 235). The product is known as cast iron and the process is a more efficient method of extracting iron from iron oxide-rich ores. However, the resulting cast iron is embrittled by the high percentage of carbon and cannot be shaped by smithing, only molten and cast into desired implements (Craddock 2003, 235).

Both methods produce a product with limited applications. The low-carbon iron from the bloomery process is soft and malleable, conversely, cast iron is hard and brittle, making them unsuitable for certain uses such as edged tools and weapons. To improve the metal's properties it was necessary to refine the iron from both processes. This involved reaching an intermediary carbon-content (0.8-2%) which provided an optimum combination of hardness, strength and malleability. Methods used in the past to achieve this involved carburising bloomery iron or de-carburising cast iron by subjecting the metal to prolonged heating cycles in a reducing or oxidising atmosphere respectively (Craddock 1995, 252-4; 1998, 43). However, these refining processes were often long and inefficient, producing non-homogeneous steels.

This is where the development of crucible steel fits in. Crucible steel manufacture allowed an unprecedented control over the production of iron-carbon alloys. For the first time, it enabled homogeneous, impurity-free high-carbon steels to be made. Two methods of production are generally proposed based on historical accounts and recipes (Bronson 1986; Craddock 1998; 2003). The first is a carburisation of bloomery iron, melted in a crucible with organic material such as leaves or wood. When fired, the carbon produced by the charred organic material is absorbed by the iron. The second method is a co-fusion of bloomery iron and cast iron, whereby both melt to produce a steel of intermediate carbon content. Both methods of production had to overcome many technical difficulties, including the ability to generate sustained furnace temperatures close to the melting point of iron and steel, as well as manufacturing crucible ceramics which could withstand this temperature (Craddock 1998, 44). The ingenuity and technical skill required represents a milestone in the development of ferrous metallurgy.

The evidence of crucible steel production comes from literary, artefactual and archaeological evidence but the relative lack of all these forms of evidence has left a substantial gap in our understanding of its origins, manufacture and spread. Pre-industrial production of steel in crucibles is known from only two geographic regions, Central and South Asia (Craddock 1998; Rehren and Papachristou 2003). Archaeological remains of manufacture has been found at several sites. The waste material of manufacturing processes are the main form of identification in the field. Unlike iron or steel products, which are turned into objects (by smithing) and transported, the slag and technical ceramic waste (furnace, tuyere and crucible fragments) is as a general rule discarded where production took place. Because of this, these residues are important as indicators of past production. They also store a lot of information. Their morphology not only allows the identification of the technology employed (smelting, crucible steel or smithing) but also give more specific clues on furnace size, shape and operating processes (Bayley *et al* 2001; Gordon 1997; Paynter 2007). Their microstructural and elemental composition can also reveal aspects of their construction methods, raw materials used and specifics about operating procedures such as temperatures achieved and constituents of the charge (Crew 2000; Lowe 1989a; Lowe *et al* 1991; Merkel 2013; Rehren and Papakhristu 2000; Morton and Wingrove 1969).

Therefore, crucible steel is formed in a liquid state, producing a fully homogenised, impurity free, eutectoid and hyper-eutectoid steel. It is a refining process of iron and steel to deliberately improve the compositional properties of the metal, enabling its use for more specialised applications. Previous research has focused on the nature and structure of the material, the accounts and recipes found in historical sources, and to a lesser extent on the production waste found on archaeological sites. However, too often has crucible steel been studied as a unique standalone technology without considering its relationship with the underlying processes used to manufacture the feedstock, iron. As a refining technology, crucible steel has a symbiotic relationship with smelting technologies and in order to understand its origins and manufacture, both must be considered in the archaeological record (Juleff 1998, 213-226; 2015, 85).

1.2 Crucible Steel in Telangana

References to the high quality of 'Indian steel' or '*ferrum indicum*' are found in Classical Mediterranean accounts as early as the second half of the first millennium BCE (Bronson 1986, 17-8; Pleiner 1971, 16-17; 2006, 68-71; Srinivasan and Balasubramaniam 2004, 50-3). However, detailed descriptions of European travellers and entrepreneurs from the 17th century, provide a clearer understanding of the nature and scale of metallurgical activity in the Indian sub-continent (Bronson 1986; Craddock 1998; Srinivasan and Balasubramaniam

2004, 60-76). These accounts were the first to reference the term 'wootz' steel and describe the production of this high-carbon steel in crucibles. 'Wootz' first appears in Pearson's 1795 lecture to the Royal Academy on Indian Steel (Feuerbach *et al* 2007, 377-8; Le Coze 2003, 117; Pearson 1795). Although there has been much deliberation about the origins of the term 'wootz' (Heath 1839; Le Coze 2003; Neogi 1914; Toussaint 2002), it is generally accepted to be a European corruption of the word for steel in south Indian languages; *wukku*/*urukku*/*ukku* (Feuerbach *et al* 2007, 378; Jaikishan 2009, 43-4; Srinivasan and Ranganathan 2004, 44). Other names commonly employed for crucible steel are *hinduwani* usually used in Arabic sources to describe Indian steel, and *pulad* (*fuladh*) which refers to the steel produced in Central Asia (Feuerbach et al 2007; Le Coze 2003).

The area now known as Northern Telangana (the study area) was regarded as one of the major production centres; reputedly producing and exporting the highest quality steel in India (Bronson 1986). The earliest reference to the exceptional properties of steel in Telangana is that of the traveller Tavernier in 1679 (1679, 674). He states that:

> "The Persians are excellent artists at damasking with vitriol, or engraving damask-wise upon swords, knives, and the like. But the nature of the steel which they make use of, very much contributes to their art, in which regard they cannot perform the same work neither upon their own nor ours. This steel is brought from Golconda, and is the only sort of steel which can be damask'd. For when the workman puts it in the fire, he needs no more than to give it the redness of a cherry, and instead of quenching it in water as we do, to wrap it in a moist linen cloth; for should he give it the same heat as ours, it would grow so hard that when it came to be wrought it would break like glass.
>
> This steel is sold in pieces as large as our one-sou loaves and in order to know that it is good and that there is no fraud involved, they cut it in two, each fragment being enough to make one sabre…. One of these loaves of steel, which would not have cost more than five or six sous in Golconda, is worth four or five abassis in Persia, and the further away one gets the more expensive it becomes: because in Turkey they sell a loaf for up to three piastres and it also comes to Constantinople, to Smyrna, to Aleppo, and to Damascus where anciently it was transported most, when the commerce of the Indies came to Cairo via the Red Sea. But today either the King of Golconda makes difficulties about letting steel leave his country or the King of Persia tries to prevent anyone from reexporting that which has entered his Kingdom.
>
> I speak thus to undeceive those people who think our scimitars and cut-lasses are made of steel of Damascus, which is a vulgar error; there being no steel but that of Golconda which can be damask'd without the steel consuming itself like ours" (Tavernier 1679, 674 as quoted in Bronson 1986, 22-3).

Although Tavernier does not specifically mention that the steel was made in crucibles, it has generally been interpreted to be crucible steel (Le Coze 2007, 339-41; Jaikishan 2009, 44). The mention of 'loaves' is particularly interesting as crucible steel ingots of a similar shape have been found in Telangana (Jaikishan 2009, 52-3; Jaikishan and Balasubramaniam 2007a, 475-6) and described in various literary sources (Bronson 1986, 28-32). The connection made to Persia and the manufacture of damask'd sabre steel is perhaps even more interesting. It fits nicely with the Damascus blades which have featured prominently within the legends of wootz steel. This account is further supported by that of Voysey's (1832) who describes the production of crucible steel in Konasamudram in present day Nizamabad district, Telangana. The description of the process will be discussed later in more depth but it is interesting that he states:

> "Konasamundram, situated about 12 miles south of the Godaveri, and 25 from Nirmul, is celebrated for its manufacture of steel, the chief part of which goes to Persia….
>
> The export, however, of the metal to Persia must be profitable, as it is sufficient to bring dealers from that country and to defray the cost and risk of travelling. We found at the village, in 1820, Haji Hosyn, from Ispahán, engaged in the speculation; and it must have answered his purpose, as he was here again in 1823, having returned in the interval to Persia and disposed of his venture. He informed us that the place and the process are both familiar to the Persians, and that they have attempted to imitate the latter without success" (Voysey 1832, 245-7).

It can be surmised that steel from this region was regarded as special, in the claim that it was the only steel that could be damask'd, and that Telangana was a major exporter of crucible steel to Persia at least in the 17th and 19th centuries. Other mentions of iron and steel exportation in the same period are found in the records of the Dutch East India Company. These attest to considerable trade conducted at Masulipatnam on the Coromandel Coast. This is particularly important as it was the chief port of the Kingdom of Golconda, now Telangana, and provides evidence of steel trade with South-east Asia, Persia and Europe (Alam 2002, 102-6; Allan and Gilmour 2000, 116-7; Bronson 1986, 22; Srinivasan and Ranganathan 2004, 68).

Historical sources and initial investigations (Jaikishan 2009; Lowe 1995) indicate that the region has a rich and diverse metallurgical history from the first millennium BCE until the advent of colonial rule (Srinivasan and Ranganathan 2004). Despite the richness of the archaeological resource, no substantial fieldwork has been carried out, nor has the large amount of technological debris evident on the surface been analysed in any depth. Indeed, "the archaeology of crucible steel production is still in its infancy, in particular in South Asia" (Rehren and Papachristou 2003, 402; Juleff 2015, 85). Research into crucible steel production will address the limitations in our understanding of the socio-cultural and technological foundation of the processes used to manufacture high-carbon steels in India in the pre-Industrial era.

The Pioneering Metallurgy Project initiated a major field survey in the research area in January 2010 (Juleff *et al* 2011). In association with the University of Exeter and the National Institute of Advanced studies (NIAS) in Bangalore, the aim of this larger project is to focus primarily on the identification and recording of metallurgical sites in the administrative districts of Karimnagar, Warangal, Nizamabad and Adilabad, which comprise Northern Telangana. The project survey achieved completion in November 2011, having generated potential for further research directions.

1.3 Aims and Objectives

No work to date has tackled the precise reconstruction of iron technological practices of this region (Jaikishan 2009, 3). To address this issue, this research will concentrate on the analysis of the primary archaeological field evidence (site data and waste materials) gathered during the Pioneering Metallurgy Project field survey, to examine metallurgical technological variation in Northern Telangana. This will tie into current research interests of technological development in the Asian context and particularly the debate on the nature and spread of ferrous metallurgy across Asia. While there has been synthetic and theoretical debate within this field (Craddock 2003; Feuerbach *et al* 2003; Glover *et a*l 1992; Juleff 2009; Loofs-Wissowa 1983), the strength of many arguments is undermined by a lack of well-founded field data.

The aim of this research is to understand the nature of iron production technologies and their development within the study area, in order to establish the reality of the technologies that made the production of high-carbon steels in crucibles possible. This includes:

- Understanding the **scale and diversity** of smelting and crucible steel metallurgical technologies.
- Examining the **spatial and temporal variations** in technology to assess the technological progression of production.
- Identifying the **inter-relationship** between smelting and crucible steel technology.
- Elucidating the **nature of resource procurement**; the use of local raw materials and the identification of imported resources.
- **Compare the evidence** in Telangana to other crucible steel producing areas in Asia to generate discussion on technological associations, origins and spread of crucible steel technology.

To address these aims, the research objectives are:

1 – To understand the underlying processes involved in iron production and crucible steel technology by reviewing current and past field research as well as historical accounts.

2 – To characterise metallurgical site types by technology and spatial distribution by reviewing the site data collected during the Pioneering Metallurgy survey.

3 – To understand the archaeological record by assessing in detail the metallurgical waste material to provide technological resolution.

4 – To use microstructural and elemental analyses to understand technological processes and material choices, and use it as a comparative tool to assess technological associations with similar sites in other parts of Asia.

1.4 Thesis Outline

In order to understand past crucible steel production and its associated technologies, the thesis starts by assessing the breadth of current and past literature relating to crucible steel production in South and Central Asia. A particular focus is placed on historical sources and archaeological evidence pertaining to manufacturing processes. The thesis then goes on to assess the metallurgical site data collected during the Pioneering Metallurgy field survey of 2010, where site types are formulated based on the dominant technological waste present. A typology of all archaeological materials is then presented and an attempt is made to identify the major metallurgical technologies employed in the region. This is supported by targeted microstructural and elemental analyses of the crucibles in order to identify manufacturing trends at a regional level and provide a comparison to crucible steel production sites in other parts of Asia.

Chapter 2 is a background to the current and past literature pertaining to crucible steel. The first section reviews some of the evidence for the origins and spread of ferrous metallurgy in the Indian sub-continent to provide a context for the development of crucible steel technology in South India. The major historical sources relating to crucible steel production in South Asia are then assessed to elucidate some of the manufacturing processes. The following sections review previous archaeometallurgical work conducted in the region as well as other parts of South and Central Asia, highlighting gaps in our understanding and providing a comparison with the archaeological evidence.

Chapter 3 sets out the physical, cultural and historical setting of the research area. Aspects such as landscape, geology, vegetation, climate, demography, land use and settlements are discussed to provide context for the location and preservation of the archaeological remains. Chapter 4 outlines the methodologies employed for the following four data chapters, including details on how the data was collected, managed and analysed.

Chapter 5 deals with the large site dataset collected during the Pioneering Metallurgy survey. Sites are resolved from the field data and placed within broad categories, forming historic, geological, ethnographic and metallurgical sites. The metallurgical sites are further divided into site types based on the dominant material waste present. General descriptive aspects such as size, location and preservation status are discussed to assess trends and provide spatial and technological resolution.

Chapter 6 assesses the large quantity of archaeological waste material collected from the metallurgical sites. The material is quantified and a typology is presented of the various forms of slags, refractory material, iron, iron ore and geological material. Their occurrence on sites are then assessed in Chapter 7 to identify technologies and their operational processes. Sites with similar technologies are mapped to identify spatial trends of technological types.

Chapter 8 provides the results of crucible fabric analyses. The microstructural and elemental analyses of the various crucible components are presented to inform on the manufacturing and operational processes of crucible steel production in the region. Microstructural and elemental variation are then compared by local crucible types as well as to other crucibles from South and Central Asia. These comparisons enable discussion on the use, spread and inter-connections of crucible steel technology in Asia.

Chapter 9 provides a broad discussion of the main research findings. The original aims and objectives are re-assessed and the value of the research is discussed. Particular attention is focused on evaluating the research findings in relation to the original aims. Discussion is fuelled by the three main research foci; the metallurgical sites, the visual assessment and scientific examination of the waste materials, and their value in identifying the scale, diversity and inter-connection of the metallurgical technologies in Telangana as well as their spatial and temporal distribution.

2 Archaeological and Historical Background

This chapter will introduce the major research themes for the development of iron and steel in India. The first section will briefly outline the evidence for the origins of iron metallurgy in the sub-continent while the following sections will deal specifically with the documentary and archaeological sources for crucible steel production in Telangana, South Asia and Central Asia.

2.1 Review of Indian Ferrous Archaeometallurgy

The emergence of iron and steel in India has perhaps received the most consideration in ancient Indian technology studies. This was fuelled by the iconic and impressive surviving artefacts, such as the Delhi iron pillar, which became the flag-bearers of the ingenuity and skill of past Indian ferrous metallurgy. Numerous authors have attempted to organise the large quantity of evidence to form theories and create models of the metal's origin, use and spread. In more recent times, the major contributors to the discussion of iron in India have been Agrawal (1999; Agrawal and Kharakwal 2002; 2003), Banerjee (1965), Bhardwaj (1973; 1979; 1982; 2000), Bhatia (1994), Biswas (1994; 1996; 2001), Chakrabarti (1976; 1977; 1979; 1997; 1992; Chakrabarti and Lahiri 2006), Gordon (1950), Gullapalli (2009; 2014; Possehl and Gullapalli 1999), Hegde (1991), Kosambi (1963), Pleiner (1971; 2006), Prakash (1991; 2001; 2002; 2011; Prakash and Igaki 1984; Prakash and Tripathi 1986), Sasisekaran (2002; 2004; Sasisekaran and Rao 2001) and Tripathi (1973; 2001a; 2001b; 2007; 2008; 2015). It has to be said, that the vast majority of the literature above has concerned itself with finding evidence for the early origins of iron production and use in India. In contrast, there is little information on later periods of production. Nevertheless, the main literary and archaeological sources of evidence will be outlined here.

There are numerous references to iron in early Indian texts such as the Buddhist Pali Canons and the *Arthasatra*, indicating its use c.600 to 100 BCE (Chakrabarti 1979; Kosambi 1963, 20; Tripathi 2008, 95-8). However, the most famous and widely debated early literary sources are the Vedic texts, most notably the *Rigveda*, generally ascribed to c.1500-1100 BCE (Banerjee 1965; Banerji 1927; 1929; 1932; Chakrabarti 1979; Gopal 1961; Pleiner 2006, 64, 66-68; Roy 1984; Tripathi 2001a; 2008, 32-34). Debate has focused on the term 'aya' mentioned in the text. Some authors have claimed that it referred to iron, and have used it as proof to suggest a relatively early date for the introduction of iron in India (Banerji 1927; 1929; 1932). However, more recent research tends to agree that 'aya' was more likely a reference to non-ferrous metals (Chakrabarti 1979; Gopal 1961; Pleiner 2006, 66-68; Tripathi 2001a, 60-65; 2008, 32-34). Other sources commonly quoted are the various mentions of Indian iron in the classical world, the most well-known are Kterias, Megasthenes, Pliny, Curtius Rufus and the Periplus of the Erythraean Sea. These are mostly dated to the later parts of the first millennium BCE and their significance in relation to iron in India has already been assessed elsewhere (Bronson 1986, 17-8; Pleiner 2006, 68-71). In general, literary sources provide little information on the production of iron in India and there are only sparse references to it before the second half of the first millennium BCE (Chakrabarti 1979).

The archaeological evidence primarily consists of numerous iron artefacts recovered from habitation and funerary sites across India. They come in a wide range of artefactual types, from weapons (swords, daggers, arrowheads, spearheads, etc.), tools (knives, axes, sickles, nails, chisels, hoes, etc.), utensils (pans, ladles, saucers, etc.) to ornaments (bangles, etc.). Some of the most well-known sites include Kausambi, Atranjikhera, Jhusi, Hastinapura, Ujjain, Rairh, Noh, Prakash, Hallur and Kumaranhalli, which range from Rajasthan to Bengal and Uttar Pradesh to the peninsula (Biswas 1996; 220-39; Pleiner 2006, 71-84; Tripathi 2001, 2008, 38-70). The majority of these finds date from the late second millennium to the mid-first millennium BCE. More recently however, there has been a proliferation of C^{14} dates that have pushed the occurrence of iron artefacts into the mid- and even early second millennium BCE (Tripathi 2008, 42), most notably from the Uttar Pradesh sites of Raja-Nala-ka-tila, Malhar, Dadupur and Lahuradewa (Tewari 2003; 2010; Tewari *et al* 2002). Mid-second millennium BCE dates have also been reported in many parts of India, including megalithic sites in South India (Tripathi 2008, 50-55).

This evidence has spurred discussions on the origin and spread of ferrous metallurgy in India. The early models favoured the idea of large scale migrations of various groups of people into the sub-continent, who brought with them new ideas and technologies (Banerjee 1965; Banerji 1929; 1932; Gordon 1950; Neogi 1914). The people most commonly referred to, were the Indo-European 'Aryans'. However, the lack of archaeological evidence pertaining to large scale migrations and the apparent continuity between pre-Iron Age and Iron Age deposits has steered the discussion away from migration theories. Models of diffusion and indigenous development of iron technology have since dominated the literature. Diffusionist's have argued for the overland spread of technology from the Iranian plateau (West Asia) to the sub-continent (Bhardwaj 1973; Kosambi 1963; Pleiner 1971; 2006, 85; Singh 1962; Tripathi 1973). In more recent years, partly based on new discoveries of very early iron finds across India, an indigenous origin and development of iron production has been proposed by many authors (Biswas 1996; Chakrabarti 1976, 1977, 1992; 1997; Datta 1992; Gullapalli 2014; Possehl and Gullapalli 1999; Prakash 2002; Tewari 2003; Tripathi 2001a; 2001b; 2008).

The nature of the evidence and the various contradicting interpretations prevents satisfactory resolution on the origins of iron in India. A thorough evaluation of the proposed models is not required here as it is not crucial to the study, but it is important to highlight some of the major shortfalls in the evidence. Our understanding is somewhat undermined by the limited archaeological context provided for early iron finds. Many of the excavations have not been published and the finds quoted only preliminary (Pleiner 2006, 71). Although some C^{14} dates have been given, there also remains a general problem with dating, making it difficult to establish a secure chronological sequence of the assemblages (Pleiner 2006, 71). Another, and perhaps greater issue is the overreliance on literary and artefactual evidence. Indian archaeology as had a tendency to focus on habitation and funerary contexts, resulting in very little evidence of iron production being uncovered. This has led to an inadequate understanding of how metal technologies functioned and evolved (Gullapalli 2014, 747; Pleiner 2006, 88-9).

Dated production sites with unequivocal evidence of iron smelting are few. The most well-known are Jodhpura (Agrawala and Kumar 1976), Naikund (Deo and Jamkhedkar 1982; Gogte 1982), Dhatwa (Hegde 1973), Atranjikhera (Gaur 1983), Ujjain (Banerjee 1965), Guttur (Rao and Sasisekaran 1997), Kodumanal (Rajan 1994; Sasisekaran and Rao 1999) and Bukkasagara (Johansen 2014). At Jodhpura, in Jaipur district, two furnaces were dated to the c.8th century BCE. At Naikund, in the Vidarbha region of Maharashtra, a small tapping furnace c.30cm in diameter, constructed of curved clay 'bricks' was dated to 6th-4th

centuries BCE. Dhatwa, in Surat district, Gujarat, revealed heaps of slag and furnace waste dated to the 4th-3rd century BCE. At Guttur, twin furnaces c.63cm wide were discovered along with slags and refractory fragments, most likely dating to the 3rd century BCE. Excavations at Kodumanal, in Tamil Nadu, revealed a bowl furnace 115cm in diameter with associated slag and tuyere fragments, dated as early as the 3rd century BCE. More recently, evidence of a small ephemeral iron-working location has been reported at Bukkasagara, in northern Karnataka, dated to the later part of the second millennium BCE.

Despite these discoveries, their informative value pertaining to past production practices is often restricted by the lack of detailed descriptions of the remains. Only limited information is provided on the furnaces and related waste material, with an almost total absence of slag and technical ceramic characterisation. In some instances, this lack of precision even prevents the nature of the practices (e.g. bloomery or smithing) to be identified (Gullapalli 2014, 741-2). In spite of the insubstantiality of production evidence, there is little question that iron was used in India as early as the middle to late second millennium BCE. However, due to the relatively few finds from this period, it is likely that intensification of use did not occur until the first millennium BCE when a larger number of iron artefacts and production sites are found.

The nature of steel development and production in India suffers from the same scarcity of evidence. The metallographic analysis of some of the artefacts recovered from habitation and funerary contexts have shown that there was carburisation of iron and heat treatment of steel by the mid-first millennium BCE (Agrawal *et al* 1990; Bhardwaj 1979; Bhatia 1994; Craddock 1998, 48; Srinivasan 2007; 689-90; 2013; Srinivasan *et al* 2009, 119-20; Tripathi 2008, 83-92). The abundant slag inclusions and heterogeneous nature of the steel suggests that steeling in this period was achieved by the solid state cementation of wrought iron. However, there have also been claims for early evidence of crucible steel manufacture, based on the discovery of a few homogeneous steel artefacts. Two swords and an adze from Taxila, dating from the late first millennium BCE to early millennium AD are the earliest finds believed to be of crucible steel (Marshall 1951, 536-7, 562-3). More recently, investigations of nine artefacts from Junnar, Maharashtra, dated from the 2nd century BCE to 2nd century AD, showed properties which are consistent with crucible steels. Eight of them had homogeneous carbon contents of 0.7 to 1.6% and were almost free of non-metallic inclusions (Park and Shinde 2013). Certainly, it is possible that steel was made in crucibles from this early date but the lack of production evidence from this period once again impedes our understanding.

The emphasis on early origin theories, which dominates Indian iron and steel literature has had a tendency to undervalue its subsequent manipulation, adaptation and elaboration (Gullapalli 2014, 748). Indeed, most research on later Indian iron and steel production has concentrated on the distinctive properties of artefacts to illustrate the skills and ingenuity of indigenous artisans. Those that have featured most prominently include the 4th-5th century AD Delhi iron pillar, the 9th-10th century AD Konark beams, and the numerous medieval iron cannons adorning forts in many parts of India (Balasubramaniam 2008). It is without question that their manufacture were impressive feats, particularly for their time, but the issue is that they have often been used to provide a technological context for the production of crucible steel (Balasubramaniam *et al* 2015; Prakash 2011; Tripathi 2007), despite the fact that the manufacturing methods were completely different. Most of these artefacts were made of forge-welded wrought or bloomery iron, unrelated to the manufacture of crucible steel. This is probably due to the general paucity of primary production evidence which provides little context for the emergence and development of crucible steel in India. It is clear that we lack understanding of how ferrous metallurgy in general developed over time, from its origin to the famous landmarks scattered across India, and in particular the manufacture of crucible steel.

Having outlined the themes and shortfalls of iron and steel research in India, it is now important to review the evidence for crucible steel production.

2.2 Review of Crucible Steel Documentary Sources

Numerous mentions, recipes and accounts of crucible steel manufacture are found in literature from the classical world to the work of 19th century European scientists and travellers. The most important of these will be outlined here, with greater emphasis on sources referring to crucible steel manufacturing processes in Telangana and other parts of South India. Bronson (1986) provides the first coherent assessment of the early primary literary evidence. This was to some extent updated by Craddock (1998) in light of more recent (at the time) archaeological findings. Literature on the subject prior to Bronson (1986), was often ridden with inaccuracies, stemming from the repeated use of misleading and mostly incorrect secondary sources. However, there have been no updated editions of Bronson's and Craddock's seminal works. Although many of their initial interpretations have stood the test of time and are still very relevant today, several new primary sources have come to light, requiring some re-assessment of crucible steel production, particularly in Telangana. It is also worth mentioning that subsequent research in the field of south Indian crucible steel (with the exception of Sri Lanka) has done nothing but reiterate the findings of Bronson (1986) and Craddock (1998).

2.2.1 Earliest references to crucible steel

There has been some debate as to the earliest reference to crucible steel. In recent years, the recipe of Alexandrian alchemist, Zosimos of Panopolis (3rd century AD) has been accepted as the first account of crucible steel production (Craddock 1998, 47; Gilmour 2009, 138; 2015, 193-4). First published in Berthelot (1888, 332) with a more recent translation provided by Giumlia-Mair and Maddin (2004, 132-133), it describes the mixing of iron with the organic parts of date palms and magnesia into a crucible. The crucible is then fired "until the iron melts and the (organic) substances are pushed into it". This seems to describe a carburisation method of crucible steel production and has close parallels with later process descriptions (chapter 2.2.2). Of particular importance are the claims that "it was discovered by the Indians, then transmitted to the Persians and in fact from there it arrived to us" (Giumlia-Mair and Maddin 2004, 133). From this, it has long been assumed that crucible steel technology is an Indian invention. However, there are no other parallels to this account and to the author's knowledge there has been no investigation or discussion as to the reliability of the source. Bronson (1986) also makes no mention of it despite an otherwise very comprehensive review of the literature.

The next accounts come from the works of Islamic writers from the 8th century AD onwards (Bronson 1986, 19; Gilmour 2015, 194). From these, we get some of the earliest mentions of steel use, trade and manufacture. The most well-known are Jabir Ibn-Hayyan's 'Book on Iron' in the 8th century (Allan and Gilmour 2000, 57-60; Howland and Gilmour 2006, 144-7;

Gilmour 2009, 141) and al-Kindi's 'Sword Treatise' in the 9th century (Hoyland and Gilmour 2006; Gilmour 2015). Al-Kindi's is particularly interesting since it provides information on different types of iron and steel used in the making of swords. These sources have featured prominently in recent crucible steel literature, with some authors (primarily Allan and Gilmour 2000; Hoyland and Gilmour 2006) arguing that they describe crucible steel production. However, as the text is often "partly cryptic and their terminology is steeped in the classical alchemical tradition" (Alipour and Rehren 2014, 236), it leaves some of the terms open to interpretation. It is particularly true of Allan's (1979, 71-4), Allan and Gilmour's (2000, 56-7) and Hoyland and Gilmour's (2006, 51-3) understanding of al-Kindi's description of 'unmined' iron, which they suggest refers to crucible steel. Irrespective of how these are interpreted, the main problem with these two early accounts is that, unlike Zosimos and later Islamic sources, they do not provide a clear recipe for steel production in crucibles. More recently, Gilmour (2009, 140-1; 2015, 195-6) claims to have uncovered a second treatise by al-Kindi 'On the Making of Swords and their Quenching' which apparently describes nine crucible steel recipes. However, the manuscript has not been published in full and is still a work in progress (Gilmour 2015, 195).

The first indisputable (Alipour and Rehren 2014, 236) description of crucible steel manufacture was that of al-Biruni's, in his 'Sum of Knowledge about Precious Stones' written in the early 11th century AD (Hassan 1978, 36; Hoyland and Gilmour 2006, 149-74). The recipe provided, has been discussed elsewhere (Alipour and Rehren 2014, 237; Allan and Gilmour 2000, 60-62) and seems to describe a two-part process, where (soft) iron, rusaktaj, golden marcasite and magnesia are placed into a crucible, which is then luted and fired until the charge is molten. The second stage is to add halilah, salt, oyster shell and pomegranate grinds, and fire for a further one hour. Another similar two-part process is recorded in Khayyam's 'Book of the New Year' in the late 11th/early 12th century AD (Alipour and Rehren 2014, 238). It is interesting to note that the mixture of iron and organic matter seems to describe a carburisation method of steel manufacture. The next mention is found in al-Tarusi's 'About the Making of Arms and Armour, War, Tactics and Army Orders' written in the 12th century AD (Allan and Gilmour 2000, 63-4; Cahen 1947, 127-8). He gives four different recipes for crucible steel production. Among them is his second recipe which is potentially the first mention of a co-fusion process (Alipour and Rehren 2014, 239). The mixing of ‘soft’ and ‘hard’ iron with magnesia and pomegranate peels where put into a crucible and melted into an egg shaped ingot (Allan and Gilmour 2000, 63; Cahen 1947, 127).

These are the earliest (known) surviving written recipes of crucible steel manufacture. We can surmise from these that steel was made by both carburisation and co-fusion from a relatively early date, pre-dating any current evidence in South India. It is important to mention that the Islamic sources are also supported by contemporary archaeological evidence of crucible manufacture in Central Asia (Craddock 1998; Feuerbach 2007; Rehren and Papachristou 2003). These are discussed in chapter 2.5. Although crucial for our understanding of early crucible steel production, these sources mostly refer to the Middle East and Central Asia. It is now important to turn to more relevant sources in the South Asian context.

2.2.2 Process reconstruction in South Asia

The next mentions of crucible steel production in the literature appear much later, in the European accounts of scientists and travellers from the 17th century AD. These arose from the growing interests of colonial powers and trading companies in the Indian sub-continent and contain a wealth of information on many aspects of Indian life, society, economy, technology and industry. They include several first-hand accounts of crucible steel production which have been reviewed in some detail by both Bronson (1986) and Craddock (1998). All known sources are listed in table 2.1 below, with the observer, date observed, location where observed, and what kind of process they described (adapted from Bronson 1986).

Table 2.1 – All known first-hand accounts of crucible steel manufacture in South Asia (adapted from Bronson 1986, 35).

Account	Date Observed	Location/District	State	Process
Havart (1693, 196)	1670's	Samtomannum/Golconda	Hyderabad	Iron melting?
Heyne (1814, 358)	1795	Malsinganhally/Chiltaldrug	Mysore	Carburisation
Heyne (1814, 361)	1795	Kakerahally/Bangalore	Mysore	Carburisation
Buchanan (1807 vol.1, 174)	1800-2	Magadi/Bangalore	Mysore	Carburisation
Buchanan (1807 vol.2, 19)	1800-2	Chinnarayandurga	Mysore	Carburisation
C.V.B. (1827)	1803	?	Mysore	Carburisation
Leschenault (1820, 334)	1817	Salem	Tamil Nadu	Carburisation
Voysey (1832, 245)	1820-2	Konasamudram/Nirmal	Hyderabad	Co-fusion
Heath (1839, 390)	1825-37	Salem/Trichinopoly	Tamil Nadu	Carburisation
Turner (1841)	1830's	Udagiri/Travancore	Tamil Nadu	Carburisation
Ondaatje (1854)	1850's	Saffragam/Kandepalle/Badulla	Sri Lanka	Carburisation
Balfour (1855)	1850's	Madgiri	Mysore	
Wood (1893, 179)	1854-7	Salem/S. Arcot/Malabar	Tamil Nadu	Iron melting?
Walhouse (1878, 195)	1870's	Salem/Coimbatore/ N. Arcot	Tamil Nadu	Carburisation
Hunter (1875, 141)	1870's	Salem/Trichinopoly/Coimbatore	Tamil Nadu	Ore smelting?
Holland (1893)	1890	Trichinopoly	Tamil Nadu	Carburisation
Bilgrami (1899, 79)	1890's	?	Hyderabad	Carburisation
Coomaraswamy (1956, 192)	1900	Hatarabage/Balangoda	Sri Lanka	Carburisation
Sambhasiva (1901, 107)	1900	Gattihosahalli/Chitaldrug	Mysore	Carburisation
Schwarz (1899, 97)	?	?	Hyderabad	Ore smelting?

It must be pointed out that Bronson (1986) questions the legitimacy of some of these accounts. Those he considers to be most dubious are the accounts of Walhouse (1878), Bilgrami (1899) and Schwarz (1899) who appear to have, at least in part, plagiarised earlier records. He also criticises Heath (1839), which is a conglomerate account of crucible steel production in general and not a process carried out in one particular place. It was written sometime after he claims to have witnessed crucible steel manufacture in Salem but he seems to depend on memory, and the similarity in some details to earlier works by Heyne (1814) suggests that some of the observations may have been borrowed from the latter (Bronson 1986, 34).

Nevertheless, these accounts provide a wealth of information. None more so than the locations of crucible steel production. It can be surmised that there are three main regions in South India; Mysore (present day Karnataka state), Salem (Tamil Nadu state) and Golconda/Hyderabad (Telangana state). To this, can be added Sri Lanka which completes all known crucible steel producing regions in South Asia. It must be mentioned here that archaeological evidence of production has been found in all four areas. The findings will be discussed in chapter 2.3.

Another consideration is the wide ranging variation in the manufacturing processes described. The variations (where stated) have been fully assessed by Bronson (1986, 36-9) but some of the most important will be mentioned here. The majority of the sources make no reference to the furnace structure, but those that do, mostly describe fully or partially enclosed hearths, seemingly not much different to a common smithing hearth. Only Voysey (1832, 246) describes a substantial structure which will be discussed further in the next section. Crucible fabrics are more consistent, with most describing a variation of clay and charred or uncharred rice husks, but charcoal (C.V.B 1827), cow hair and oil (Schwarz 1899) as well as furnace and crucible fragments (Voysey 1832, 246) have also been suggested as temper. Variations in crucible size vary from 1 pint to 8 inches long and 5 inches thick (Bronson 1986, 36). The shape of the crucibles have been described as conical (Buchanan 1807, 19; Heyne 1814, 358; Sambhasiva 1901, 107), guava-shaped (C.V.B 1827), pine-shaped (Voysey 1932, 246), pear-shaped (Holland 1893) and flowerpot-shaped (Schwarz 1899, 978). The number of crucibles placed in the furnace varies from 1 to 59, while the firing time is from 2 to 24 hours, or until liquefied (Bronson 1986, 38). After the process has been completed, various accounts describe the cooling of the crucibles with water while still hot (C.V.B 1827; Heyne 1814, 358; Sambhasiva 1901, 107), air cooled outside the furnace (Buchanan 1807, 174; Coomaraswamy 1956, 193; Heath 1839, 392; Voysey 1832, 247) or left to cool in the furnace (Hunter 1875, 149; Schwarz 1899, 978; Wood 1893, 179).

Perhaps more relevant to this study, are the descriptions of the crucible charge. The majority of accounts describe the placing of iron with wood and/or leaves. C.V.B (1827) adds rice husk to that mixture while Wood (1893) only mentions iron, and Turner (1841) describes a content of iron and bone ash. Voysey (1832) is the only one who mentions the addition of two different kinds of iron with slag, while Schwarz (1899) describes the placing of ore with slag and charcoal powder. These recipes have led to the belief that there were two major manufacturing processes in South Asia (Bronson 1986, 39-40; Craddock 1998, 52). The carburisation of iron with organic matter which has been described in Tamil Nadu (Salem), Karnataka (Mysore) and Sri Lanka, and a co-fusion of iron and cast iron, only described by Voysey (1832) in Telangana (Hyderabad). Schwarz's (1899) account is believed to have either been a mistake while copying Voysey (1832) or a deliberate fabrication to disguise the origins of the data (Bronson 1986, 45; Craddock 2003, 242-3). A review of his account by the author agrees with Bronson's assessment and will therefore not comment on it further. Voysey's account will be reviewed in more detail in the next section.

Another interesting revelation is the varied use of the final product. Whereas crucible steel has often been associated with the manufacture of mythical 'watered' swords, the accounts give other uses. Of particular importance is Buchanan's (1807, 151-152) claim that the steel was used for musical wires, of which the city of Chinapatnam in Karnataka state supplied the majority of South India. It is also worth mentioning that no account "states or implies that the South Indian wootz they saw being made exhibited the classic watered patterns of true Damascus when forged into weapon blades" (Bronson 1986, 40). Crucible steel was probably produced for a variety of different end uses, not always weaponry. In some cases, it is likely that the most valued property of crucible steel was not its carbon content but its homogeneous inclusion-slag free structure. Perhaps, this is the case in Wood's (1893) account which only sees iron placed in the crucible.

As an additional note, it is evident that, with the exception of Konasamudram in Telangana (Voysey 1832), the scale of the manufactures as described seemed quite small, "no more than cottage industries orientated to a purely local market" (Bronson 1986, 41). Having outlined the major findings of crucible steel manufacture in the wider South Asian literature, it is now important to turn to the literary evidence for the region of study – Telangana.

2.2.3 Process reconstruction in Telangana

The first-hand eye-witness accounts of crucible steel manufacturing form the first indisputable proof of steel being made in crucibles. With regards to Telangana, the most well-known source is Voysey's (1832) description of crucible steel production at Konasamudram. In fact, all the literature on the subject post-Bronson (1986) has taken Voysey's (1832) description of the co-fusion process as representative of all past production in the region (Allan and Gilmour 2000; Craddock 1998; Feuerbach 2007; Juleff 1998; Lowe 1995; Rehren and Papachristou 2003; Srinivasan 2007). This mainly falls on Voysey's (1832, 246-7) report of two different kinds of iron being charged into the crucibles; one from Mirtpalli, that is amorphous, porous and reddish-grey in colour, and another from Kondapur, that is moderately compact and of a brilliant white fracture. These have been interpreted as bloomery low-carbon iron and white cast iron respectively (Bronson 1986, 43-4; Craddock 1998, 55). Indeed, Voysey's account, in its detail, is very convincing and there is no reason to doubt his observations, particularly since he states that he visited Konasamudram on several occasions. However, there may be some conjecture as to iron with a 'brilliant white fracture' referring to cast iron. The fact that it is 'moderately compact' also raises some doubts, as cast iron as we know it today is formed fully molten and solidifies in a compact state. It is also let down by a lack of substantial proof of cast iron smelting in India, which needs to be addressed briefly here.

The indigenous production of cast iron in India has received too little attention (with the exception of Craddock 2007), and very little is known about 'how' or even 'if' it was manufactured. Certainly, no archaeological evidence to date has unearthed remains of a cast iron technology (Craddock 2003; 252; 2007, 600-1). As Craddock (2007, 600-1) suggests, this absence of physical evidence may be due to the general lack of excavation of iron smelting sites in India. It is also possible that it was produced in indigenous bloomery-type furnaces (Bronson 1986, 43) and that the archaeological remains are indistinguishable from other iron smelting technologies. This is also plausible, as shaft furnace experiments conducted by Tylecote *et al* (1971) have been reported to produce very high carbon iron. Production in this method might also account for the less consolidated nature of the iron described by Voysey.

Literary evidence on the subject is lacking (Craddock 1998; 2003; 2007), but there are some reports which may support this theory. Holland (1892, 148) for example, describing steel production in Salem (Tamil Nadu), states that "in the manufacture of wrought iron, certain easily fusible beads of iron are produced and melt off as shot. These are in reality highly carburized particles, or cast iron, and it is from these that the steel is made". Although he does not mention their use in a crucible process, it certainly suggests that cast iron, as a by-product of the bloomery process, was known and exploited by Indian workers. Another account is that of Heath's, published by Mushet (1840), in which he reports findings of grey cast iron production in Trinomally (Tamil Nadu) for use as crucible steel feedstock. Not much detail is provided and the second-hand nature of the account raises doubts on its veracity. Nevertheless, it indicates a specialised technology where a small charcoal-fuelled blast furnace (c.2.5m high and 0.45m wide) was used to produce cast iron. His statement that the iron produced was ‘without perfect separation’ suggests that it was not fully consolidated and could once again explain Voysey’s account. However, research on the subject is lacking and a comprehensive review of the literature as well as targeted archaeological surveys and excavations would be required to ascertain the nature of its indigenous production in India.

Despite the obvious gaps in our understanding of cast iron production in India, the concept of co-fusion has found purchase in more recent literature, primarily due to other supporting documentary evidence of similar processes (Allan 1979, 71-4; Allan and Gilmour 2000, 72-5). As mentioned earlier, al-Tarsusi’s second recipe describes the mixing of a soft and a hard iron, but perhaps an even more convincing account, and contemporary to Voysey’s, is Massalski’s (1841, 297-300). He describes crucible steel production in Iran in which he states that iron, white cast iron and a little silver were mixed (Allan and Gilmour 2000, 73-5, 535-9). In light of this, it seems probable that a co-fusion method did exist but the lack of supporting archaeological evidence in the Indian context, prevents the confirmation of this assertion.

The fact that co-fusion in Telangana is based on Voysey’s sole account, cannot be ignored, and it would be bad practice to rule out other methods. This is particularly relevant in light of new literary evidence which promises to be valuable in this context. A first-hand description of the crucible steel process in the province of Samtomannum, Golconda (Hyderabad) was given by Havart in 1693 (196-201). Havart was an employee of the Dutch East India Company and his account now forms the earliest known process description, not only in Telangana but also the whole of South Asia. A translation from Dutch has been published in Alam (2002) but due to the difficulty in separating it from the author’s interpretation, our own translation is provided here. Text in [brackets] are an addition by the translators Lowe and Wagenaar (pers. comm., 2016).

> “**A pertinent description of how iron is made.**
> **About the iron and its preparation as it is done in the region of SANTOMANNUM.**
> The iron ore is generally found a man’s height deep at the foot of the mountain in that place. For removal, the ore is broken up with crowbars and heavy chisels. It is then heaped up with alternate layers of wood. The heap is then set on fire until the wood is consumed. This ‘burned’ iron ore is then broken up with wooden sticks into pieces, grit and fragments about the size of coarse sand mixed with angular lumps.
> After that they make a tube furnace about an el [69cm, from van Dale 1976] high in a square shape about a foot [Amsterdam foot 28.3cm, from van Dale 1976] wide which is fixed flat on the surface of the earth. In the earth under the tube furnace, a pit about ten

fingers deep is dug in the shape of a tub. Situated on this furnace at the place where it rests on the earth, a small oblong hole is made in order to insert two pipes of two bellows with which a continuous blast is blown into the above-mentioned clay furnace. Then the furnace is filled up to the top with charcoal. A half sawed-through water pot is placed on top of the furnace in such a manner that the mouth of this pot fits onto the mouth of the furnace, giving this half-pot thus nearly the shape of a hopper [funnel shape] which widens toward the top. This hopper is also filled with charcoal. It was set afire from above and below. From time to time, afterwards, a little of the roasted ore is tossed into this hopper onto the coals.
This ore is smelted in the fire and [the iron] flows downward between the coals toward the aforementioned hollow pit in the earth. Having started up early in the morning, they continue to replenish the furnace with charcoal and to put in the iron ore until the evening. As a result, a whole lump of iron is found down below in the hole. Then they break the furnace to pieces and take out the glowing lump and bring it out onto a flat surface where it is cut with broad axes into as many pieces as they want bars. They put these pieces into the fire. Then they beat out bars, working out the impurities by beating – or at least most of the impurities. The iron is then kept to be utilized or sold. The thinner the bars and the longer they are worked in the fire, the better the iron. These bars weigh about 3 – 4 pounds.

In order to make the iron into steel.
To prepare steel from the iron.
When they want to make this iron into steel, they pour water onto the aforementioned glowing lump of iron until it is cold. Then by beating and hammering, they smash it into pieces. After that they take clay crucibles with lids which they will seal up tightly. Beforehand, they have placed inside each one a certain weight of the iron. Further, they dig a four-sided hole in the ground about one and a half man's height deep and about three els wide at the bottom. The upper part slants together at the top so that the top remains about one el wide. On top [of this hole] a tube of the same shape, straight outside with the inside slanting upwards, is placed flat on the ground. On either side of the tube at the place where it rests on the ground, a hole is extended slanted towards the bottom in order to lay two tuyeres [blaas-pijpen – blow pipes] on either side so that a strong fire can be made. When this furnace and the crucibles are well dried in the sun, they take up the crucibles with long tongs and set them in the very bottom of the furnace so that they stand firmly. They then fill the furnace with charcoal all the way to the top of the tube. The charcoal is ignited and the top of the tube is covered so that the flame won't come out. The charcoal is replenished now and then. This stoking and blowing lasts 24 hours until the iron is refined into steel. While this is going on, from time to time, a person on a high platform looks into it. He lets out the rising dross, shifts also the crucibles taking out the broken ones, dumping the materials into other fresh crucibles and setting them again into the furnace. All of this is carried out with the long tongs mentioned above. When the whole twenty four hours have passed in this way of stoking and blowing, they let the fire cool by itself. The crucibles cool off and in each one a small lump of steel is found.
These lumps are then reworked into ingots and into klaverstaal, that is, into ingots with points just like a clover-leaf. Ordinary ingots and clover-leaf ingots do not differ markedly in quality, however, the klaverstaal is flatter and rings somewhat more. Obviously, it could be seen that it was somewhat finer because it had been beaten thinner". (Havart 1693, 199-201 as translated by Lowe and Wagenaar pers. comm. 2016).

This report, being a relatively recent find, has not yet been integrated into the discussion of crucible steel production in Telangana. Hence, it is important to discuss it further here and provide comparisons with Voysey's account. The basic processes described by both Voysey (1832) and Havart (1693) are summarised in table 2.2. Although Havart does not mention the size, shape or construction of the crucibles, he does provide a detailed description of the furnace structure and firing process. Voysey goes into much more detail about the crucibles, stating that they are pine-shaped, made of granitic clay with old furnace/crucible fragments and rice husks. Archaeological evidence at Konasamudram supports this description (Lowe 1989a; 1989b) and will be discussed further in chapter 2.3. Both agree that the crucibles are luted or sealed but only Voysey mentions that the lids are perforated. There are other significant differences in both accounts. Voysey describes the furnace as a circular clay structure 4-5 feet high and 5 feet in diameter, sunk 2 feet below ground. Havart's is a four sided hole dug to one and a half man's height with a tapering width from c.2m at the base to c.07m at ground level. He also describes another structure on top, of a similar internal shape but with flat exterior sides. Voysey, notes the use of four bullock skin bellows placed at the top of the furnace, while Havart only two at ground level. However, they both suggest that the blast is forced down into the furnaces. Both also state that the fuel used was charcoal and that the process lasted 24 hours but only Havart describes the furnace being covered to stop the flame coming out. During the process Voysey states that crucibles are arranged and steadied with a long iron rod. Havart suggests that the broken crucibles are removed and their charge placed in new ones which are then re-introduced to the furnace with the aid of long iron tongs. Both convey that the fire is allowed to subside but only Voysey mentions that the crucibles are taken out of the furnace to cool.

These differences already suggest a much different process of crucible steel manufacture but none more so than Havart's description of the crucible charge, which consists of just bloomery iron. It is not possible to say whether the addition of organic matter (for carburisation) or cast iron (for co-fusion) was inadvertently omitted from the description, but due to the detailed nature of the rest of the process, it seems unlikely. Another important difference, is the way in which the final ingots were worked. Voysey says that the ingots were covered in clay and annealed in the furnace several times, while Havart states that they were beaten into clover-leaf shaped ingots. This suggests that the end products were different and perhaps intended for different uses. Perhaps the steel described by Havart did not contain as much carbon and was immediately workable. The fact that no other substances were added to the charge would suggest that carburisation was done inside the furnace, perhaps explaining its covering. However, it is uncertain how this would work if the crucibles were, as mentioned, sealed. Another possibility is that the organic matter in the crucible clay was enough to carburise the iron inside (as suggested by Rao *et al* 1970), but since no information is provided on their manufacture, it cannot be proved. It is also possible, as mentioned in the previous section, that carbon content was secondary to the slag/impurity-free nature of the steel.

What is certain, is that the differences in processes, shape and size of the furnaces indicate two different methods of crucible steel manufacture. It is now possible to argue that crucible steel production in Telangana was not exclusively a co-fusion process but likely encompassed more process variations to produce different end products. Both accounts are separated by close to 140 years and based in different locations, therefore, it is likely that manufacture also varied temporally and geographically in the region. The purpose here is not to refute Voysey's description or indeed try and disprove co-fusion, but highlight that there may have been alternate methods operating in Telangana. Due to the lack of archaeological evidence and other literary sources, research in Telangana in the past has too often relied on the singular account of Voysey. This is also applicable to crucible steel research in general, whereby process re-constructions have too often emulated literary evidence rather than the archaeological evidence. Although informative, there is ambiguity in all the records and it is important to recognise the short-comings on which we base our interpretations. This is not helped by the relative paucity of archaeological evidence in South Asia and the lack of systematic scientific examination of metallurgical waste. It is now important to review this archaeological evidence.

Table 2.2 – Summary of crucible steel processes in Voysey's (1831) and Havart's (1693) accounts. Note - ? is unstated by author.

Process Description	Voysey (1832)	Havart (1693)
Furnace shape	Circular; 4-5 feet high; 5 feet diameter; sunk 2 feet below ground	Four sided hole in ground 1.5 man's height deep; c.2m wide at bottom tapering to c.0.7m at ground level; at ground level a structure is built of the same shape which tapers to the top
Furnace clay	Granitic clay	?
Tuyeres	Four?	Two, placed in holes in furnace at ground level, on either side, facing down the furnace
Bellows	Four bullock skins; nozzles placed at right angles resting on upper edge of furnace – to force blast downwards	? [presumably two]
Fuel	Charcoal	Charcoal
Other features	Screen of mud to protect workers	Furnace covered so that flame does not come out
Crucible shape	Pine-shaped	?
Crucible size	Various sizes – depending on intended purpose of steel	?
Crucible clay	Granitic clay; fragments of old furnaces and crucibles; chaff of rice and oil	?
Lids	Luted with lid of same material; perforation in lid	Sealed up tightly
Crucible manufacture	?	Dried in the sun
Crucible charge	*Kanch* or glass formed in the process and ore for flux; two kinds of iron	Iron (unworked bloom cooled with water and smashed)
Number of crucibles	?	? placed at bottom of furnace with long tongs
Process while firing	Crucibles arranged and steadied with a long, stout iron rod	Broken crucibles are removed and their charge placed in new crucibles which are put into the furnace again
Length of firing	24 hours	24 hours
Cooling	Fire allowed to subside, then crucibles taken out, placed on ground and allowed to air cool	Let the fire cool by itself, the crucibles cool off [not mentioned in or out of furnace]
Ingot	Cake of steel of great hardness; average weight 1.5 pounds	Small lump of steel
Ingot processing	Cake covered in clay and annealed in the furnace for 12 or 16 hours – repeated up to 4 times	Reworked into ingots and klaverstaal – hammered into clover-leaf shape

2.3 Review of Previous Archaeometallurgical Fieldwork in Telangana

Despite the historical accounts (discussed above), describing the manufacture of crucible steel in Northern Telangana in the medieval, post-medieval into the colonial period, little archaeological work has been undertaken to elucidate the nature and extent of this metallurgical production. This section will outline the most recent archaeometallurgical investigations in this region, starting with field archaeology and surveys, then ethnographic work, and finally, scientific examinations of relevant archaeological materials.

2.3.1 Field Archaeology and Surveys

No archaeometallurgical research was undertaken prior to the ground-breaking work carried out by Thelma Lowe in the late 1980's. In fact, there is a complete absence of research from the historical colonial accounts in the 17^{th} to 19^{th} centuries AD, to the fieldwork carried out by Thelma Lowe. Lowe was a mature doctoral student of the University of California, Berkeley, with a long-standing immersion in Indian culture, science and technology (Figure 2.1). Unfortunately Lowe's findings were never fully published before her passing in 2011. Her published work is limited to four articles, three of which focus on the scientific analysis of crucible fabrics (Lowe 1989a; 1989b; Lowe *et al* 1991). Nevertheless, a brief summary of her fieldwork as well as initial interpretations of the data was provided in Lowe (1995). Lowe's survey, conducted over three field seasons (1987-9), comprised an area approximately 6000km^2 situated north of Hyderabad with a focus on Nizamabad District. She claims to have identified 74 iron smelting sites, of which 14 had evidence for crucible steel production, as well as 8 sites of historical mining activity and 17 probable ore sources (Lowe 1995).

Little information is presented on the sites themselves but she characterised the smelting activities into two groups based on apparent ore types smelted, banded magnetite sites and laterite sites. To support her observations, she provides an extract of Voysey's (1832) account of crucible steel production at Konasamudram where he described a co-fusion process mixing two types of iron; one smelted from 'iron sand' and another from 'iron clay' which she interprets as magnetite and laterite respectively (Lowe 1995). The proximity of crucible steel manufacturing sites to both types of smelting suggests that they may have provided the feedstock for this technology, representing "an intensification of the pre-existing iron processing industry" (Lowe 1995). Although she only provides a brief interpretation of her fieldwork data, her work forms the foundation which fuelled subsequent investigations in the area. It was the first attempt to survey, characterise the nature, and assess the extent of ancient ferrous metallurgical activities, making her work significant in several ways. The only previously known crucible steel production site was Konasamudram and the identification of numerous other sites suggested a much more widespread, large scale and complex enterprise. Another significant contribution was the identification of smelting sites in the vicinity and the start of accessing the inter-relationship between the production of the feedstock (iron) and the final product (crucible steel).

Figure 2.1 – Thelma Lowe surveying a metallurgical site (photo courtesy of G. Juleff).

Dr S. Jaikishan, an historian native to the research area, was the next person to survey ancient iron and steel production sites. Over the period of one year he visited over 1100 villages in the northern Telangana districts of Karimnagar, Adilabad, Nizamabad and

Warangal. The findings were synthesised in a series of recent articles (Jaikishan 2007; 2013; 2015; Jaikishan and Balasubramaniam 2007a; 2007b) as well as a book published in 2009 (Jaikishan 2009). He claims to have found evidence of ancient iron and steel manufacture in over 425 of these villages of which 325 were in Karimnagar district (Jaikishan 2007, 453). Although his work was not exhaustive (Jaikishan 2007, 458), it does attest to the widespread tradition of ferrous metal production in the area. Unfortunately, Jaikishan only provides a place-name catalogue of these sites (Jaikishan 2007, 453-6; 2009, 8-15) without any specific locational information, site descriptions or indeed a characterisation of the types of archaeometallurgical materials observed.

However, he does make several important general observations, giving a first impression of metallurgical residue locations and their preservation status. Namely, that the visible remains of ancient production are slags, crucibles and other smelting debris usually found in the centre of villages, in nearby fields or in abandoned habitation sites in forest areas (Jaikishan 2007, 449; 2009, 15). The majority of the sites are heavily disturbed, scattered or partially removed, either by new constructions in villages, or by intensive cultivation in surrounding fields. In some cases slags were found within the mud walls of houses and forts. On the other hand, the forest sites are the best preserved due to the lack of human interference. He also states that slag heaps were commonly found close to roads but that they were also subject to disturbance as the slag was found suitable for road repairs and filling ditches (Jaikishan 2007, 449-53; 2009, 15-19; 2013, 117).

His work also revealed that some village names were “etymologically related in the regional language (Telugu) to terms associated with iron and steel manufacture” (Jaikishan 2007, 456). Of notable interest are words such as *inumu* meaning iron, *cityamu* for slag, *kammāri* is blacksmith, *kolimi* for furnace and *muddā* for bloom. These find their way into village names such as Inukūrthi, Cityāla, Kāmmāripally, Kolimkunta and Muddāpalli (Jaikishan 2007, 457; 2009, 24; 2013, 116-7). Of notable interest is that all these villages have significant slag heap remnants, pointing to their importance as iron smelting production sites (Jaikishan 2007, 457).

Although Jaikishan does not provide detailed material descriptions, he does review some of the material evidence observed on some sites. The majority of the material appears to be smelting slags, furnace wall fragments, tuyeres and crucibles. He also notes that the debris is different on some sites which may be evidence for earlier iron production. One such site is Ranamkota (Buggaram) in Karimnagar but no further site information or interpretations are offered (Jaikishan 2009, 32; Jaikishan and Balasubramaniam 2007a, 468). He also mentions *in situ* furnace remnants in the forests of Adilabad which may differ from other remains found in villages, but once again no more information is provided. From the furnace wall fragments observed, he proposes that all smelting occurred in circular clay furnaces and the iron produced in the solid state, direct method (bloomery process). The presence of both large quantities of tapped slag and large plano-convex bottom furnace slags leads him to suggest that both tapping and non-tapping furnaces were employed (Jaikishan 2009, 33-6; Jaikishan and Balasubramaniam 2007a, 468-70).

With regards to crucible steel production, Jaikishan lists the most important sites as Ibrahimpatnam, Jagtial and Kalleda in Karimnagar District, as well as Konasamudram, Konapuram, Basheerabad and Dindurthy in Nizamabad District, and Nirmal, Kalleda and Rebbanapally in Adilabad District (Jaikishan and Balasubramaniam 2007a, 473-4). Since these sites are all situated close to the most famous site of Konasamudram, he suggests that Konasamudram might have been the nucleus of crucible steel production (Jaikishan 2009, 45; 2013, 118). He also notes that there is significant variation in the size of crucibles found but no detailed measurements or information of their distribution are given. He proposes that the size of the crucibles were directly correlated to the end application of the ingot. Smaller ingots being used for smaller objects such as small blades while larger ones might have been intended for larger blades (Jaikishan and Balasubramaniam 2007a, 472). Indeed, three ingot examples in his private collection range in weight from 400g to 2000g, attesting to the significant difference in ingot size and weight (Jaikishan 2013, 120). In addition to the technological debris found at these sites, he reports the continuation of wootz implement usage by various artisan groups. This includes blacksmith anvils which are capped with a layer of wootz steel to provide a harder, more durable surface as well as toddy tapper knives, *khater* and *khanjer* implements. He also states that people in the region traditionally possess swords and other warfare objects made of wootz, handed down as family heirlooms (Jaikishan and Balasubramaniam 2007a, 476-7) and stresses the need for these tools and artefacts to be studied and catalogued.

Jaikishan's work was most valuable in identifying and assessing the sheer scale of past metallurgical activities in the region. However, it lacked considerably in detail, with no in-depth characterisation of the sites and the waste material observed. To address this, the Pioneering Metallurgy Project was instigated in 2010, shortly after Jaikishan's (2009) book was published. This was a joint project between the National Institute of Advanced Studies (NIAS) in Bangalore, India and the University of Exeter in England. Its aim was to survey as many ancient metallurgical sites as possible relating to iron and steel technology in the northern Telangana districts of Adilabad, Nizamabad, Karimnagar and Warangal. Although the purpose was to explore known sites identified by Jaikishan, new sites were occasionally discovered. The survey took place in a period of six weeks from January-March 2010 and the preliminary results published in an interim report (Juleff *et al* 2011). The site data and the materials sampled during the survey are the focus of this study and will therefore not be discussed further here. The survey methodology and subsequent treatment of the site data is presented in chapter 4.2.

2.3.2 Ethnographies

Dr Jaikishan is the only person to have documented and published ethnographic work relating to archaeometallurgy in the region. The primary focus has been on smithing communities with knowledge of ancient iron and steel production. Of particular interest to this study are the accounts of two senior blacksmiths, Mattela Gangaram from Ibrahimpatnam and Mandalogi Gangaram from Konapuram, who were interviewed by Jaikishan during his survey. The interview transcript of Mandalogi Gangaram can be found in Jaikishan (2009, 101-8; Jaikishan and Balasubramaniam 2007c). These modern ethnographic accounts describe certain interesting aspects of ancient crucible steel production. Although wootz was not made during their lifetimes, the two smiths remember parts of the process described to them by their fathers and witnessed the better preserved remnants of furnaces when they were young. A summary of Mandalogi's account will be provided here (Jaikishan 2009, 50-3; 2013, 120-1).

The clay for the crucibles was collected from a special 'clay pond' in the forest approximately 1.5kms away from the village. It was collected dry and processed by soaking it in water, allowing the larger particles to sink and using only the fine silt which settled on the top. This fine clay was then mixed with rice husks gathered from the paddy fields. The crucible bodies were then shaped and allowed to dry in the shade. Once dried, the charge consisting of bloomery iron pieces, one piece of *thangedu* wood, ground *pulyeilauku* green leaves and a small amount of borax was placed in the crucible. They were then covered by a clay lid of conical shape and once again allowed to dry in the shade. The furnaces were circular, three to four feet in diameter with two to four tuyeres on opposite sides and powered by buffalo skin bellows operated by hand. The crucibles were placed on a bed of charcoal and fired for 24 hours although they were lifted and rotated several times during this process with the help of long tongs. They were kept at a stable temperature for a further 8-10 hours and then allowed to cool naturally before opening. This is particularly interesting as it seems to imply a carburisation process of crucible steel production which is in conflict with the current trends that overwhelmingly ascribe the co-fusion process to steel manufacture in this region (chapter 2.2.3).

Part of Jaikishan's work has also tackled some of the social aspects of iron and crucible steel production, particularly amongst the blacksmithing communities still present today. He states that the settled village blacksmiths are part of the *pancannam varu* community of the *Visvakarma* caste, which comprises five groups; blacksmiths, goldsmiths, bronzesmiths, carpenters and sculptors (Jaikishan 2009, 59; 2015, 244; Jaikishan and Balasubramaniam 2007b, 482). Ancient iron smelters often associated themselves with blacksmithing after the decline of the industry but they do not hold the same social privileges or positions of the traditional smiths even to this day. The descendants of iron smelting communities are known as *muddakammari* (lump iron makers) whereas the smiths are known as *kammari*. He states that these communities used to live outside villages close to the natural resources (forests and ore sources) required for the manufacture of iron but eventually became assimilated into village life and the smithing communities when smelting ended (Jaikishan 2009, 60; 2015, 244; Jaikishan and Balasubramaniam 2007b, 482-3). He also suggests that parts of the community may be itinerant, moving from place to place depending on work opportunities, as evidenced in other neighbouring regions such as the *agariyas* (Jaikishan 2009, 60-1; Jaikishan and Balasubramaniam 2007b, 483).

Of particular interest are some of the social practices performed by these smithing communities. He notes that many of the ancient wootz production centres have temples dedicated to the goddess *Mammayee* (*Mammayi* or *Mammaya*). Of notable importance are the villages of Kalvala and Ibrahimpatnam in Karimnagar district and Konasumudram in Nizamabad district (Jaikishan 2009, 62, 65; 2015, 244-5; Jaikishan and Balasubramaniam 2007b, 485). *Mammayee* is considered to be the goddess of metal work with *mamma* or *amma* meaning mother and *ayee*, *aya* or *aye* meaning iron in Pakrith and Sanskrit languages (Jaikishan 2009, 62; 2015, 244; Jaikishan and Balasubramaniam 2007b, 485). Regular meetings take place in these temples, presided over by elder blacksmiths, where community problems are resolved and important decisions taken (Jaikishan 2015, 245). Jaikishan (2009, 62-4; 2015, 245-6) and Jaikishan and Balasubramaniam (2007b, 485) also describe the annual *Mammayee* festival that takes place during the Telegu New Year (late March to early April) in some of the villages. The festival lasts 11 days and starts with the lighting of the sacred oil lamps in the temple. All community members bring the tools of their trade (one or two implements) and place them on a stand next to the goddess idol where they stay for the remainder of the festival. The festival involves several feasts and processions of the idol through the village and ends with the tying of the sacred thread on participant wrists and on the tools. It is interesting that as well as blacksmiths, bronze and goldsmiths also took part. In Konasamudram, two *Mammayee* temples are found, one for the blacksmith community and another for the bronzesmiths (Jaikishan and Balasubramaniam 2007b, 486-7).

Jaikishan's work in the area has shown that the traditions of iron and steel manufacture and its working have partly survived, not only in the social stratas and practices of blacksmith communities but also in oral accounts of elder members of the community. However, he is not precise on how he attained the majority of this information and only one interview transcript is provided. The Pioneering Metallurgy Project also aimed to address this by recording the surviving knowledge of local residents in a more systematic way (Neogi and Jaikishan 2011). This incorporated many interviews of members of the blacksmith community. This work was taken over and expanded by Tathagatha Neogi, a member of the original survey team and student of the University of Exeter, as part of his PhD thesis (Neogi forthcoming).

2.3.3 Scientific Investigations of Archaeometallurgical Waste

Scientific investigation of the manufacture of iron and steel have mostly concentrated on the microstructural and elemental analyses of the finished products – wootz artefacts and ingots (Kumar *et al*, 2007; Park and Shinde 2013; Srinivasan 2007; Srinivasan *et al* 2009; Verhoeven 1987; Verhoeven *et al* 1996; Wayman and Juleff 1999). Comparatively little attention has been given to the large quantities of manufacturing waste material found in the villages, fields and forests of Telangana. In fact, there are no in-depth macro-morphological or scientific analyses of any of the smelting remains identified by both Lowe (1995) and Jaikishan (2009). The only scientific investigations have focused on the crucibles and crucible fabrics employed in the manufacture of wootz, and even these are few and almost entirely focused on the residues of one site, namely Konasamudram. The bulk of the research was conducted by Lowe (1989a; 1989b; Lowe *et al* 1991) and later added to by Balasubramaniam *et al* (2007) as part of Jaikishan's post-survey research.

Lowe's work comprised the analysis of nine crucible fragments from Konasamudram. She was the first to describe in detail the macro-morphology and ceramic fabric microstructure of the crucibles from Telangana. Her first two papers (Lowe 1989a; 1989b) concentrate on the physical components of the crucibles as well as a description of their microstructure as seen under an optical microscope. Her later publication (Lowe *et al* 1991) expands on her earlier findings, providing greater resolution of the composition of the ceramic fabrics with the use of X-ray diffraction (XRD) and scanning/transmission electron microscopy (SEM/TEM). More detailed descriptions of crucible morphology and fabric composition will be provided in chapters 6 and 8 but the main findings from Lowe's research will be outlined here.

Of particular interest are Lowe's descriptions of fused crucible fragments. She observed that some of the smaller crucible fragments were fused together in groups of threes, which she describes as 'triple crucible' covers (Lowe 1989a, 733-4). She suggests that these crucibles were made independently, individually charged but luted together and then fired as a unit. She argues that this would have produced an ingot with a coarser crystal structure than an ingot of similar size produced in an independent crucible. This would have been an intentional process to make a steel suitable for a particular end usage or tool which required these properties (Lowe 1989a, 734-5). However, it is not known how many of these fused crucibles she observed and it is not inconceivable that they might have bonded unintentionally during the firing process (assuming that they were tightly packed in the furnace).

The crucibles Lowe analysed are made of two distinct fabrics, the main refractory vessel fabric and the coarse cover fabric constituting the lid and external glaze. They are relatively squat in shape, resembling small cups. The covers or lids are conical in shape and have parallel tool marks, most likely from handling with tongs. They have an internal chamber varying from 2.5 to 12cm in diameter (Lowe 1989a, 733; 1989b, 238). The internal surfaces can be divided into two sections. The bottom portion, where the ingot formed, is covered with a thin layer of glassy slag and there are remains of a glassy fin where slag solidified above the ingot and broke when the crucible was opened. Above this fin, the upper portion of the inner chamber, there are numerous small iron prills or droplets up to 5mm in size, often suffering from post-depositional corrosion. These prills are also abundant on the internal underside of the lid cover (Lowe 1989b, 239-41).

Lowe describes the main vessel fabric as black in colour and composed of charred rice hulls and clay. It has a porous texture comprised of many irregular and spherical voids. The irregular voids are influenced if not formed by the rigid silica relics of charred rice hulls, while the fine spheroidal pores are produced by the reduction of ferric oxide to ferrous oxide and eventually to metal (Lowe 1989a, 736; 1989b, 241). This is evidenced by the many fine dispersed iron prills found in the glassy matrix of the crucible fabric, most likely formed during the long firing process in a reducing atmosphere. Dense networks of accicular mullite crystals were also reported within the glassy phase. Lowe and her co-authors claim these would have improved the vessels' mechanical strength (Lowe *et al* 1991).

Lowe argues that the physical and elemental properties of rice hulls made them an appropriate constituent of the refractory material. The cell walls of the hulls were composed of very fine silicon carbide particles surrounded by carbon and retained their approximate shape when coked. The high silica content increased the stability and refractory nature of the clay while the dissolved elemental and particulate carbon (responsible for the black colour of the fabric) offered higher thermal conductivity (Lowe 1989a, 736-7; 1989b, 244-5). Hence, the clay was strong enough to resist the high temperatures but also conductive enough to allow heat into the crucible to melt the charge.

The coarse cover fabric, made of a number of different components, served as an additional protection to the high temperatures. Lowe's analyses show that the cover fabrics consisted of broken refractory fragments, coarse quartz and feldspar grains in a glassy matrix, with many pores (Lowe 1989a, 737; 1989b, 246). The glassy phase is continuous and has many suspended iron prills, with a concentration of larger prills at the base of the covers/lids (Lowe 1989b, 247).

Balasubramaniam, Pandey and Jaikishan (2007) further reinforced the findings made by Lowe but expanded their study to encompass crucibles from five different sites in Telangana. These were Konasamudram, Konapuram, Rebanapalli, Kalleda and Ibrahimpatnam. One main vessel fabric sample per site was analysed using SEM-EDS and XRD, taken from the crucible base (Balasubramaniam *et al* 2007, 652-3). Their XRD analyses confirmed that the crucible fabric was mostly made of silicate and mullite. Phases containing alkali and alkaline earth elements were only present in very small amounts (Balasubramaniam *et al* 2007, 654-5). The same microstructural features identified in Lowe's examination of the crucible fabric were identified in all crucibles. Only minor differences in porosity between samples were noted which may have been "related to the way and proportion in which the clay, rice husk and water were mixed originally" (Balasubramaniam *et al* 2007, 657). They stress that the similarity of the crucible manufacture indicates the spread and possible continuity of wootz steel making tradition in the region (Balasubramaniam *et al* 2007, 649).

Their study reveals several additional findings worth mentioning here. They provide a more comprehensive description of the rice hull remnants and notice that they often preserve their original shape in a basket-weave like structure. Although they agree with Lowe, that these are mostly pure silica in cristobalite crystalline form, they also identified small quantities of Ti, Ca and K which they suggest are impurities from the inorganic portion of the rice husk (Balasubramaniam *et al* 2007, 663). In addition, they identify fibres, 10-20 micron in diameter, associated with these basket-weave rice hull remnants. Analyses of the fibres suggest that they are pure carbon. They propose that these are the cellulose fibres commonly found in rice husks which transformed during firing and that part of their role was to increase the conductive properties of the ceramic material (Balasubramaniam *et al* 2007, 659-62).

The scientific examinations conducted by Lowe and Balasubramaniam *et al* on the crucibles found in Telangana identified the major mineral phases and microstructures of the main vessel fabrics. This not only gave valuable insight into the production of the crucibles themselves (i.e. the choice of raw materials employed) but also informed some of the processes involved in the production of crucible steel. It is also important to mention that the conical lids and the identification of rice hull temper support the observations made by Voysey (1832). However, these studies had limitations, leaving several gaps which should be mentioned here.

With the exception of the four samples analysed by Balasubramaniam *et al* (2007), all of the crucibles analysed were from one site, Konasamudram. Even the analyses conducted by Balasubramaniam *et al* comprised only one sample per site, so potential variation at site level has not been investigated. Taking into account the large number of crucible steel production sites discovered by both Lowe (1995) and Jaikishan (2009), there is scope for a larger sample size incorporating crucibles from more sites. This would provide a better understanding of crucible steel manufacture in the region. In addition, despite Lowe's (1989a; 1989b) description of three main crucible components; the main vessel fabric, the cover or lid fabric and the internal glassy slag, the majority of microstructural and elemental analyses have concentrated on the main black crucible fabric. In fact, Balasubramaniam *et al* (2007) made no attempt to analyse either cover fabric or internal glassy slag, while Lowe only briefly describes the microstructural phases of the cover fabric. A thorough investigation of these two components would certainly increase our understanding of the crucibles and crucible steel manufacture. The analysis of the internal glassy slag in particular could enable the identification or at least provide clues on the types of raw materials constituting the crucible charge. It is also worth mentioning that no quantitative elemental analyses have been published for any of the crucible fabrics or other components. Quantitative bulk compositions would be useful to compare crucible manufacture trends, not only at inter-site and intra-site level but also provide comparisons to crucibles found in other regions across South and Central Asia.

Perhaps the greatest gap is the total absence of material characterisation of other metallurgical technologies. Crucibles are the only technological waste to have been analysed with a complete lack of information on all other metallurgical debris scattered across

Northern Telangana. Both Lowe and Jaikishan attest to the large heaps of smelting and crucible steel debris but no-one to date has tackled the systematic recording, description and cataloguing of this material. These include slags, furnace lining and tuyeres employed in the production of both iron smelting and crucible steel manufacture. The morphological analysis of these materials has the potential to reveal many unknown aspects of the ancient metallurgical technologies, how they evolved and how they inter-connected. “All too often crucible steel is studied in isolation as a specialist technology. In contrast, being able to examine crucible steel within wider, regional patterns of ferrous metallurgy, adapted to supplying a wide range of end-users, will afford a better understanding of the techno-cultural role of crucible steel” (Juleff 2015, 85). This is what will be attempted in this study, with an aim to try and fill some of the gaps identified in previous research.

2.3.4 Summary

The vestiges of ancient iron smelting and crucible steel production have been found in northern Telangana by Lowe and Jaikishan. Their work has demonstrated the large scale nature in terms of production intensity and spatial distribution of the metallurgical activities that once took place in this region. They were the first to identify the remains of both iron smelting and crucible steel production and start assessing their inter-relationship. The discovery of numerous crucible steel manufacturing sites is particularly relevant as it shows that the technology was more widespread than previously thought, indicating a possible continuity of a wootz steel making tradition in the region. However, both surveys had considerable shortfalls. Lowe’s work was never fully published and Jaikishan’s survey only yielded a place-name catalogue of the sites with no specific locational information, site descriptions or assessment of the metallurgical residues present.

Scientific analysis of the archaeometallurgical residues has been undertaken by both Lowe and Balasubramaniam *et al*. The morphological and scientific analysis of the crucibles have revealed similarities with Voysey’s account. The crucible lids at Konasamudram were conical in shape which fit with Voysey’s description of pine-shaped crucibles, while the crucible fabrics were found to be rice husk tempered, once again as described by Voysey. However, these analyses were limited in the sense that only the crucible main body fabrics were investigated. Future analyses of the lid fabrics and the internal glassy slags have the potential to reveal many more aspects of crucible steel production. Despite the numerous sites identified, the majority of the crucibles analysed were from one site, Konasamudram. Once again, there is scope for analysing more crucibles from more sites which would provide a better comparison of crucible steel technology across the region. The largest gap, however, is the total absence of material characterisation of other metallurgical technologies. None of the slags, furnace remains or tuyeres were investigated. In part due to the lack of material assessment and detailed descriptions of sites, no evidence for cast iron production has been identified. The few microstructural and elemental analyses of the crucibles have also not been able to identify by what process the steel was manufactured. Therefore, there is currently no archaeological evidence that supports or refutes a co-fusion method of crucible steel production in Telangana.

2.4 Review of Archaeological Evidence for Crucible Steel elsewhere in South Asia

The production of crucible steel was not confined to the research area. As discussed in chapter 2.2, documentary sources suggested production took place in other parts of South Asia, primarily in the states of Karnataka (Mysore) and Tamil Nadu (Salem), as well as Sri Lanka. More recently, this has been supported by archaeological surveys and excavations which have identified several production sites in these areas. The archaeological evidence will be outlined here with the aim of providing a more complete technological context for crucible steel production in Telangana. Of particular importance will be assessing the evidence for Bronson's (1986) claim, that the process employed in these regions (carburisation) was different to the one employed in Telangana (co-fusion), which he bases entirely on literary sources. To date, two sites in Tamil Nadu, one in Karnataka and two in Sri Lanka have been identified.

2.4.1 Tamil Nadu (Salem)

The earliest evidence for crucible steel manufacture has been claimed at **Kodumanal** in Tamil Nadu. According to Srinivasan (2007, 685), the crucible remnants at Kodumanal date as far back as 300 BCE, and form the "earliest known evidence for the use of crucible methods in ferrous processing". However, the use of these crucible remains is contentious and the evidence provided needs to be reviewed here.

The site itself was excavated between 1985 and 1996. The excavations revealed evidence of significant industrial activity, ranging from iron smelting and crucible steel-making to semi-precious stone working (Sasisekaran and Rao 1999, 265; Srinivasan 2007, 685; Rajan 2015). This site is of particular significance when taking into consideration Pliny's historical mention (in his *Natural History*) of Roman importation of 'iron from the Seres', which has been interpreted by various authors as the South Indian kingdom of the Cheras – 3rd century BCE to AD 3rd century (Sasisekaran and Rao 1999, 263-4; Srinivasan 1994, 50; 2007, 675). The site is located close to the ancient Chera capital, Karur, on the ancient trade route connecting the capital to the western coast (Sasisekaran and Rao 1999, 264).

The excavations consisted of two groups of trenches, c.300m apart, situated both at the southern and northern end of a habitation mound (Sasisekaran and Rao 1999, 265; Rajan 2015, 68). The southern part of the excavation revealed the remains of an iron smelting bowl furnace, 1.15m in diameter and 0.65m in depth, along with slag and tuyere fragments (Sasisekaran and Rao 1999, 265-6; Rajan 2015, 68-9). The northern part revealed two large oval-shaped furnaces, of which one appeared to be unused, surrounded by an additional 12 small furnaces. The main furnace had a diameter varying between 1 - 1.12m, it was 0.4m deep and had burnt clay walls 0.2m thick. The surrounding furnaces had a diameter around 0.3m at the mouth, with a central depression. They were connected to the main furnace by burnt clay pipes. A vitrified broken crucible was found *in situ* within one of these small furnaces, along with many other small crucible fragments found nearby (Sasisekaran 2004, 29; Srinivasan 2007, 685; Rajan 2015, 69-70). The small furnaces were interpreted as being used to store the crucibles once removed from the main furnace, allowing them to cool slowly at low temperatures. The absence of any tuyeres also led to the belief that the operation was not powered by bellows but by natural draught (Sasisekaran 2004, 30; Sasisekaran and Rao 1999, 267; Rajan 2015, 69-70).

The crucibles from Kodumanal were investigated and analysed by Srinivasan (2007, 685-6). Some were small, bowl-shaped, open crucibles which she suggests could have been used to cast precious metals. However, one crucible fragment stood out from the others as it was vitrified and blackened, of closer resemblance to crucibles used to manufacture steel found at other south Indian sites (Srinivasan 2007, 685-6). The fabric was friable suggesting that it was perhaps less refractory than other steel manufacturing crucibles. Although no metallic prills were observed, the subsequent analysis of the fabric by EPMA-WDS showed no significant amounts of precious or base metals but some iron-rich regions with traces of titanium. Srinivasan (2007, 686) proposes that these iron-rich regions are significant enough to confirm that the crucibles were used for ferrous metal processing. However, no further descriptions or analyses are given.

The remains at Kodumanal are interesting and, if the interpretations are correct, it would be the earliest tangible evidence for crucible steel production to date, and the only example of natural draft powered crucible furnaces. However, due to the archaeo-technological importance of such claims and the distinctive character of the evidence, several points of caution have to be mentioned here. None of the published reports provide a clear explanation of how the technological remains were dated. In addition, there is no contemporary archaeological evidence to provide comparative data and unlike other crucible steel manufacturing processes in South India, there is no contemporary documentary evidence describing the process. In fact, all later literary accounts clearly state the use of bellows (Sasisekaran 2004, 30) and it is unknown if natural draft furnaces would permit furnace conditions to reach temperatures high enough for crucible steel manufacture. The last and most important critique is the lack of any absolute scientific evidence proving steel was made in the crucibles. Iron, being the most common metal on earth, is commonly found within most soils and clays. Therefore, the presence of iron-rich regions within the crucible fabric may not be exceptional, particularly if the firing process was at least mildly reducing. In the absence of metallic prills, their use or function cannot be positively identified. The importance of this site would certainly warrant a more comprehensive evaluation of the remains and full scientific examination of the archaeological materials.

The second and more compelling field evidence for crucible steel in Tamil Nadu was discovered in 1991 by Srinivasan (1994, 52; 1997, 111; 2007, 677; Srinivasan and Ranganathan 2004, 112-21; Srinivasan *et al* 2009, 117). A mound of technological debris about 25m x 8-9m and up to 5m high was discovered close to the village of **Mel-siruvalur**. As well as slag and pottery remains, a significant quantity of crucible fragments were observed.

Slag and crucibles were also found scattered around an old canal approximately 0.5km from the mound (Srinivasan 1994, 52; 1997, 112; 2007, 677; Srinivasan *et al* 2009, 117). Two trenches c.70m away from the main deposit revealed tapering tuyere fragments, furnace remnants and large tap slag cakes (c.200mm in size) with clear flow textures. Srinivasan interprets (1994, 54; 2007, 679-80) this as the likely location of furnace operations but no other information is provided. It is also important to note that the metallurgical activities at Mel-siruvalur remain undated.

The Mel-siruvalur crucibles have been described and analysed by Srinivasan (1994; 1997; 2007; Srinivasan *et al* 2009). The fragments had similar morphological features as crucibles from other South Indian sites, including those from Konasamudram in Telangana. They were described as aubergine-shaped, closed crucibles with thick covering lids of c.70mm diameter. The base of the lids had fibrous imprints indicating that the crucibles would have been charged with organic material. The exterior of the crucibles were covered with a thick black ash glaze suggesting that they were fired in highly reducing conditions. Vertical flat ridges seen along some the crucibles also suggests that they may have been stacked together in the furnace. In a similar fashion to the Konasamudram examples, the internal surfaces had a circumferential glassy slag fin in the middle of the crucible. Below this fin, a thin layer of honeycomb textured glassy slag lined the surfaces, while above the fin, rusty patches with small metallic prills were prominent. These rusty patches and prills were also present on the base of the lids (Srinivasan 1994, 54; 2007, 678-9; Srinivasan *et al* 2009, 117-8).

The subsequent scientific analysis of the crucible fabrics by SEM-EDS, revealed many similarities with the crucibles from Telangana (see chapter 8). This consisted of a black, porous fabric with coked rice hull relics dispersed within a glassy matrix network (Srinivasan 1994, 56; 2007, 681). The rice hull remains were present either as voids, charred carbonaceous remains or fused glassy remains. The analysis of the fused networks around the charred hulls revealed them to be of a relatively fixed 38-39% Si composition. Although Srinivasan (2007, 681) states that the SEM-EDS analyses were not suitable to quantify carbon, she suggests that these areas are likely to be silicon carbide (SiC_4) in a silica and alumina rich glassy matrix. The analysis of the exterior ash glaze revealed quartz inclusions not identified within the interior cross-section, leading her to suggest that the crucible exteriors may have been rolled in crushed quartz as an additional protection from furnace conditions (Srinivasan 2007, 680). However, no analyses or comments were made of the crucible lid fabrics, it is thus unclear whether they were made of the same material, or, like the Konasamudram crucibles, made of a coarser quartz-rich fabric. Metallic prills from the exterior and interior of the crucibles, up to 3-4mm in size, were analysed by EPMA-WDS, SEM-EDS and etched. These revealed hyper-eutectoid steels comprising a lamellar pearlite eutectoid surrounded by an intergranular network of cementite and cementite needles on former austenite grain boundaries (Srinivasan 2007, 682-3; Srinivasan *et al* 2009, 118-9). The estimated carbon content of the prills was around 1-1.2%, providing strong evidence that these were indeed crucibles used for the manufacture of steel (Srinivasan 2007, 682-3; Srinivasan et al 2009, 118-9).

2.4.2 Karnataka (Mysore)

The third South Indian site is **Ghattihosahalli** in Karnataka. A comprehensive site survey and review of both archaeological and literary evidence has been published by Anantharamu and co-authors (1999), while crucible analysis results have been reported in Rao *et al* (1970) and Freestone and Tite (1986). This strong archaeological and scientific data is further supported by a late 19th century account describing crucible steel manufacture at Ghattihosahalli (Sambasiva 1901). This first-hand account provides many valuable insights. In the absence of scientific dating, it proves the process was active in the late 19th century and combined with Buchanan's accounts in the same area a century earlier (in 1801), which failed to report any form of activity at Ghattihosalalli, suggests that activities started sometime earlier in the same century (Anantharamu *et al* 1999, 17-18). Sambasiva's account (1901, as quoted in Anantharamu *et al* 1999, 22) suggests a carburisation method of steel production whereby "50 to 55 bits of wrought iron from three to four inches in length are introduced into an equal number of specially prepared clay crucibles with few bits of wood-*thangadichakkey* in each and the mouth of the crucibles closed by clay". He goes on to say that "these crucibles are then laid in the form of a semi-conical heap into an ordinary smith's furnace worked by bellows for about five hours" and then cooled suddenly by water. Of further importance are his claims that the wrought iron used as feedstock is produced and procured locally. Production was only active over a two month period per year due to want of demand and that about 45 lbs. of steel was produced daily (Anantharamu et al 1999, 22).

The remains at Ghattihosahalli are concentrated on one main heap north of the village. This heap extends 250m E-W, up to 40m N-S with a height between 3m and 6m. The technological residues observed comprises slag, furnace wall, tuyere and crucible fragments, amounting to an estimated 15000m^3 (Anantharamu *et al* 1999, 17). The crucibles were conical in shape with a tapering diameter from the top to the base. Many of the crucibles had slumped during the process, resulting in an oval opening ranging from 30 to 60mm in diameter. They had a maximum internal depth of around 150mm and the wall thicknesses ranged from 10 to 15mm (Anantharamu *et al* 1999, 18). The crucible morphology and fabric composition was very similar to crucibles found in other parts of South India. Unfortunately, the internal morphology of the crucibles have not been described anywhere.

The main fabric was black in colour and porous, constituting a clay heavily-tempered with rice husk (Anantharamu *et al* 1999, 18; Freestone and Tite 1986, 53-4; Rao *et al* 1970). The crucible matrix consisted of a very-fined grained mullite mass with some quartz grains altered to cristobalite (Rao *et al* 1970, 13-16). The charred organics within the crucible reduced the iron oxide in the clay to form iron in the metallic state (Freestone and Tite 1986, 54) which precipitated within the matrix as very fine iron prills (Rao *et al* 1970, 16). In addition to crucibles, green glassy slags were observed similar to those found on most other South Asian sites. These were analysed by Anantharamu *et al* (1999, 18) who concluded that they probably resulted from the vitrification of the furnace lining by the intense heat of the process.

2.4.3 Sri Lanka

The primary source of archaeological evidence for crucible steel production in Sri Lanka is the research conducted by Juleff from the late 1980's to the present. Crucible steel sites were found and recorded during the Samanalawewa Archaeological Survey, the results of which have been published in full in Juleff (1996; 1998) and Juleff *et al* (2009). Although the focus of the survey was to initially record 'village' smelting sites and crucible steel production described in ethnographic accounts (Juleff *et al* 2009), the aims were somewhat eclipsed by the discovery of the ‘west facing’ group of 1st millennium wind-powered iron smelting sites (Juleff 1996; 1998). Nevertheless between the Samanalawewa Survey and subsequent survey in the Knuckles Range of the Central Highlands, two crucible production areas were identified (Juleff 2007), one at Mawalgaha (Juleff 1990; Wayman and Juleff 1999) and another at Hattota Amune (Juleff 2015).

In order to gain a fuller understanding of crucible steel production in Sri Lanka it is important to briefly mention some of the most important documentary sources related to its manufacture. These have been discussed in greater detail by Juleff (1990, 39-42; 1998, 14-8) and Wayman and Juleff (1999, 26-7). The first reference to Sri Lankan steel is found in al-Kindi’s book on the Qualities of Swords. Written in the 9th century AD, he highlights the importance of *Serendib* (Sri Lankan) steel in the manufacture of Arabic swords. He also names four areas (Yemen, Fars in Iran, Khorasan and Mansura in Pakistan) where this steel was commonly employed (Juleff 1990, 39; Wayman and Juleff 1999, 26). Although this attests to the prized qualities of Sri Lankan steel, it does not specifically state that it was produced by the crucible process. The first and most important accounts of crucible steel production were provided by Ondaatje in his contribution to the Ceylon Almanack of 1854 (Ondaatje 1854) and Coomaraswamy in his 1908 book Mediaeval Sinhalese Art (Coomaraswamy 1956, 192-3).

Ondaatje (1854) reports that production of crucible steel was in decline and that it only constituted “a little inland trade” and “now made only in Saffragam and Kandepalle in the District of Badulla”. He describes a carburisation method of crucible steel production which involves: “introducing a small bar of good iron into a clay mould of a tubular form which they call *covery* with pieces of dried wood of the *Cassia auriculata*. The open end of the tube is afterwards closed with clay, and it is placed in a charcoal fire for two hours, by which process carbon is supplied to the iron, which is converted to steel”.

Coomaraswamy (1956, 192-3) witnessed crucible steel production approximately 50 years later and describes the process in greater detail. He states that at the time he observed the process it was extinct, but that two very old men at Alutnuvara “keep up the tradition, and are able to demonstrate the process when required”. He describes the furnace as being a ground level semi-circular hearth filled with charcoal and defined by a low clay wall about 6 inches high. The crucibles are “about 8 inches long, two inches in diameter, and a quarter inches in thickness". The charge consists of a piece of iron and chips of wood (*Cassia auriculata*), the crucible is then closed with a perforated lid and fired. Once the crucibles are ready, they are picked up with long iron tongs and shaken to see if the steel is liquid and then laid down to cool. In addition to a more detailed description of the process, Coomaraswamy (1956) provides the only known photographs of a crucible steel manufacturing process (Figure 2.2).

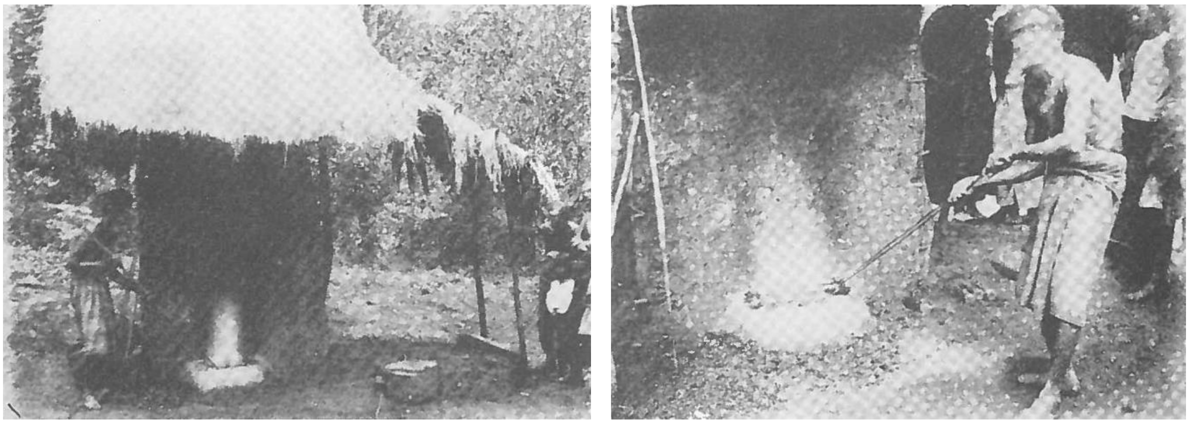


Figure 2.2 – The only known photographs of a crucible steel furnace in operation taken by Coomaraswamy in the early 20th century (Coomaraswamy 1956, plate LIII).

Juleff states that these ethnographic accounts "were very much in mind when the Samanalawewa Archaeological Survey commenced" (Wayman and Juleff 1999, 27) and that one of the primary aims "was to relocate Coomaraswamy's steel making site, and also to search for other, similar sites in the locality" (Juleff 1990, 42). This led to the discovery of crucible remains in the village of **Mawalgaha**, about 2.5km from Alutnuvara, both of which were mentioned by Ondaatje and Coomaraswamy. The archaeological evidence present and the ethnographic accounts of local smiths suggested that this was indeed the location of the crucible steel demonstration witnessed by Coomaraswamy (Wayman and Juleff 1999, 28-9). This is further supported by the calibrated radiocarbon dates which gave a date range between 1528-1955AD, suggesting that production would have been contemporary to both accounts (Juleff 1998, 94).

The site is located in the centre of the village, in a garden overlooking paddy fields. The remains of crucibles were found in the exposed banks of the garden, visible over a distance of 16m and 1.5m height (Juleff 1990, 42; 1998, 90; Wayman and Juleff 1999, 28). The top

0.3m surface layer of the bank was dominated by large plano-convex or convex-convex cakes believed to be from an iron smelting or smithing operation. Beneath this layer, was a thick deposit of crucible fragments densely packed in a soil matrix (Juleff 1990, 43; Wayman and Juleff 1999, 28). Another surface scatter was found approximately 25m from this site. The material observed included smaller crucible fragments, tuyere fragments and small green and blue glassy slag lumps (Juleff 1990, 43; Wayman and Juleff 1999, 28-9). Survey of the surrounding area and other sites mentioned in Ondaatje's account revealed no other crucible steelmaking evidence. The exception is Kosgama village were Juleff claims to have identified a disperse scatter of very small crucibles in a cultivated paddy field (Juleff 1998, 90; Wayman and Juleff 1999. 29) but no more information is provided.

The crucible fragments at Mawalgaha conform to the descriptions reported by both Ondaatje and Coomaraswamy. They varied in size and completeness, from small base or wall fragments to almost complete crucibles. They are of a long slender shape (tubular) with rounded base (Figure 2.3) and the lid fragments have four or more small pierced holes, as described by Coomaraswamy (Juleff 1998, 90-1; Wayman and Juleff 1999, 28-9). The maximum length recorded was 186mm with an average external diameter of 34mm and walls 4-12mm thick (Juleff 1998, 91). The fabric is of a uniform black colour, made of a mixture of rice husk and clay. The exterior of the crucibles are covered with a layer of green, blue or black glassy slag which appears to have flowed down to collect in thick viscous lumps around the base (Juleff 1990, 43-4; 1998, 91; Wayman and Juleff 1999, 29). The interiors are lined with a thin layer of glassy slag and two glassy slag fins. The first is a circumferential fin delineating the top of the ingot when the crucible was upright in the furnace. It is situated at approximately a third (~60mm from the base) of the crucible height. The second is a longitudinal slag fin running at a right angle from the first, running the length of the crucible (Juleff 1990, 44; 1998, 91; Wayman and Juleff 1999, 29).

This correlates with Coomaraswamy's description that the crucibles were laid down to cool and would have created an ingot shape "more convenient as a starting material for forging a blade or cutting tool" (Wayman and Juleff 1999, 29). Indeed, two ingot fragments were also recovered from Mawalgaha with this characteristic elongated shape (Figure 2.3). The subsequent analyses of these fragments revealed eutectoid to hyper-eutectoid microstructures with an estimated carbon content above 1%. They contained few slag impurities and were completely dendritic, consistent with cast structures (Wayman and Juleff 1999, 30-4).

Figure 2.3 – Crucible section and bloom fragments recovered from Mawalgaha (photo courtesy of G. Juleff).

A second location with evidence of crucible steel manufacture was discovered in a subsequent survey, conducted in 1996. The site of **Hattota Amune** is situated on the eastern flank of the Knuckles range of hills of central Sri Lanka (Juleff 2015, 79). It is located in a house compound where an abandoned c. 5x5m gem pit was found in the vegetable garden exposing a thick deposit of slag, pottery and crucible fragments. The subsequent excavation aimed to cut back the exposed sections to record and sample the deposit debris. Crucibles were found in two context layers along with an abundance of slag (mostly plano-convex cakes) and pottery. The examination of the pottery gave a tentative date range of 5th-8th centuries AD (Middle Historic period) which was confirmed by a series of radiocarbon dates suggesting that crucible steel making took place “in the second half of the first millennium AD, beginning at least in the 7th century” (Juleff 2015, 84).

The crucibles were fragmentary and ranged significantly in completeness. The best preserved examples indicate that they were small in size, narrow necked rounded flasks (Figure 2.4). The crucible diameters varied from c.15mm at the neck to 45mm at the body with an internal depth of at least 65mm (Juleff 1998, 217; 2015, 85). The walls are thin (c.3-5mm) with a dark brown to black, slightly coarse but uniform-textured fabric. The exterior surfaces are coated with an uneven blueish-green vitrification, which, in a similar fashion to the Mawalgaha crucibles, accumulates at the base. A vertical glassy slag fin was also observed on the interior surfaces of better preserved examples suggesting that they were not laid down to cool like their Mawalgaha counterparts (Juleff 1998, 217; 2015, 84-5). In addition, bluish-green/pale cream amorphous glassy slag or vitrification fragments were found which resembles the material adhering to the exterior of the crucibles (Juleff 2015, 85).

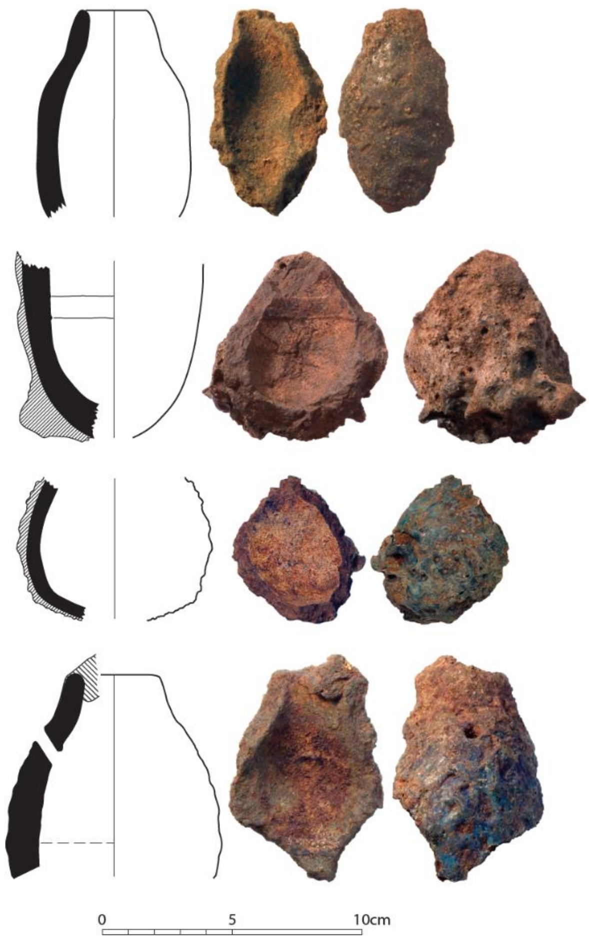


Figure 2.4 – Crucible fragments from Hattota Amune (Juleff 2015, 84).

These two Sri Lankan crucible steel production locations were very distinct from one another and represent technologies separated by at least 1000 years. Of particular interest is the presence of slag at both sites, more specifically an abundance of large plano-convex cakes. These were first interpreted by Juleff (1990) as waste of an unrelated iron smelting operation but were more recently reinterpreted as smithing waste (Juleff 1998, 93; 2015, 85). This suggests that crucible steel was not the sole occupation and likely functioned alongside other technologies. It is important to mention that these sites were small by comparison to the large crucible sites found in South India. Juleff (1996; 1998; Juleff *et al* 2009) identified large scale ancient iron smelting activities but despite numerous field surveys in many parts of the island, the evidence for crucible steel production remains sparse (Juleff 1998, 94). She suggests that "smelted metal was processed at local smithing sites that also had a minor capacity to refine high carbon steel in crucibles" (Juleff 2015, 85). Indeed, crucible steel production would fall short of the *Sarandib* steel requirements implied by al-Kindi. There are also no contemporary crucible steel manufactures in the Samanalawewa area for this period (Juleff 2015, 85). Juleff (1998, 94) highlights that the term 'steel' in the context of the Indian subcontinent is all too often automatically prefixed with the word 'crucible' and suggests that due to the lack of evidence pertaining to large scale crucible steel production in Sri Lanka, *Sarandib* steel was the likely output of the west-facing wind-powered iron smelting furnaces (Juleff 1996, 62; 2015, 85).

2.4.4 Summary

Several crucible steel production sites have been identified in South Asia. Most, with the exception of the Sri Lankan sites, have not been scientifically dated. The earliest site is Hattota Amune, found in Sri Lanka, dated to the 7th century AD. The others, particularly Ghattihosahalli (Karnataka) and Mawalgaha (Sri Lanka) are datable from eye witness accounts to the 19th century AD. The evidence at Kodumanal (Tamil Nadu) is contentious and in the author's opinion there is not enough evidence to prove that crucible steel was manufactured there. Mel-siruvalur (Tamil Nadu) is convincing as a crucible steel production site but the remains have also not been dated. This leaves a considerable time gap between the earliest Sri Lankan date and the later steel production witnessed in the 19th century AD. To date, no explanation has been proposed, but the absence of dating and of systematic surveys in the regions are the cause of the lack of evidence during this long time period. Besides the dating issues, it is important to point out that the majority of the sites discovered have not been placed in wider technological contexts. The lack of surveys in the surrounding areas, with the exception of Sri Lanka, have left these sites isolated from other contemporary technological traditions. The sites were either found accidentally, such as Mel-siruvalur, or were specifically targeted due to eye witness accounts of production, as at Ghattihosahalli.

The most striking consideration is the similarity of all deposits and the waste materials. All sites, with the exception of Ghattihosahalli, are small with relatively little waste material present. This suggests that the production was only small scale, perhaps just enough to serve local requirements. All sites also had evidence of iron smelting and/or smithing activities, suggesting that the feedstock was produced on site. The crucibles are also generally similar, only varying in size and shape. The fabrics are all dark grey to black in colour, porous and tempered with rice husks. All examples have similar black glassy slag fins and small steel prills adhering to their interior surfaces. The similarity is extended to the crucibles found in Telangana which have comparable fabrics and internal glassy slags. There is no evidence from the morphology of the crucibles that suggests a difference in steel manufacturing process such as carburisation or co-fusion. Most sites also have green glassy slag remains mixed with the crucible waste, suggesting that the processes were similar. At this stage, all the South Asian crucibles appear to belong to the same crucible steel manufacturing tradition, in operation over a long time period and with considerable variation in crucible shape and size (i.e. volume). However, it must be pointed out that only a few scientific studies have analysed the crucible remains and most of these have concentrated on the main crucible fabric. No analyses of the internal glassy slags and lids have been published which limits any further comparisons between the crucibles.

2.5 Central Asia and the wider context of crucible steel production

The archaeological remains pertaining to crucible steel production in South Asia discussed above have to be placed in the wider context of contemporary crucible production in other parts of the world. To date, the only other geographical area to provide evidence of early crucible steel production is Central Asia, particularly Turkmenistan and Uzbekistan. In the last 30 years or so, numerous production sites have been discovered and excavated. The results of which, as well as the scientific analysis of the metallurgical material waste, have been reported. The majority of the research conducted in this region has focused on three sites, Merv in Turkmenistan (Feuerbach 2002; Feuerbach *et al* 1997; 1998; 2003; Feuerbach and Griffiths 1995; Herrmann and Kurbansakhatov 1994; Merkel 2013), and Akhsiket and Pap in the Ferghana valley of Uzbekistan (Papakhristu and Rehren 2002; Alipour *et al* 2011; Rehren and Papakhristu 2000). More recently, further evidence has been found at Chāhak in Iran (Alipour and Rehren 2014). Crucible production has also been noted at Kuva and Termez in Uzbekistan and Semirechye in Kazakhstan, but significantly less work has been conducted on these sites and their remains (Papakhristu and Rehren 2002, 69; Rehren and Papachristou 2003, 397).

A thorough review of all archaeological and scientific sources cannot be provided here but good summaries of all sites and their residues have been published in Craddock (1998), Feuerbach (2007) and Rehren and Papachristou (2003). The aim is to synthesise the most important findings, providing a technological comparison with the evidence from South Asia, focusing on the nature of the archaeological deposits and the crucible remains.

The manufacture of crucible steel in Central Asia, as in southern Asia, is supported by several historical sources describing the production of crucible steel in the region, particularly during the Islamic period. A thorough review of these literary accounts has already been published elsewhere (Feuerbach 2002; Alipour and Rehren 2014) and does not need to be re-assessed here. The most well-known sources are al-Biruni and al-Tarsusi, writing in the 11th and 12th centuries AD (see chapter 2.2.1). Another account was that of Massalski, who saw crucible steel being made in Uzbekistan in the first part of the 19th century AD (Allan and Gilmour 2000, 73-5, 535-9; Feuerbach 2007, 320). However, unlike many South Asian sites, which for the most part rely on documentary sources for dating (chapter 2.4), all Central Asian crucible remains (Chāhak being the exception) come from dated contexts. They belong to the same broad early medieval period between the late 8th and late 12th centuries AD (Rehren and Papachristou 2003, 395; Papakhristu and Rehren 2002, 69).

An important difference between Central and South Asian sites is the physical location of the remains. Evidence of crucible steel manufacture in Central Asia is typically found in significant urban settlements and hill-forts, far from obvious sources of iron ore (Rehren and Papachristou 2003, 395; Papakhristu and Rehren 2002, 69). In contrast, the remains in South Asia are often found in small village settlements close to abundant natural resources (chapter 2.4). Feuerbach (2002, 177) suggests that the Central Asian sites were more reliant on the import of raw materials than South Asian sites and that trade in these materials was an important part of the process. Although few studies have dealt with the procurement of resources in the South Asian context, Lowe (1995) has observed evidence for local iron ore extraction in the vicinity of the Telangana sites. This is supported by Jaikishan's (2009, 50-2; 2013, 120-1) ethnographic work which provides accounts of the raw materials (clays, wood and iron ores) being sourced locally (see chapter 2.3.2). The physical locations of crucible steel manufacturing sites, in relation to urban settlements and availability of natural resources, has received too little attention in the literature and deserves to be investigated further. It is possible that production in Central Asia was more centralised, situated closer to the markets of large administrative settlements where the goods were traded and sold. Whereas, evidence from South Asia points to manufacture in more rural environs, which may have required the finished product to be exported longer distances. However, to develop these arguments further would require more research to be conducted on the socio-economic contexts of both regions.

The primary source of crucible steel manufacturing evidence are the archaeological remains of the crucibles themselves. The morphological aspects and scientific analysis of fabric microstructure and composition has been published widely for Central Asian crucibles, particularly those from Merv (Feuerbach 2002; Feuerbach *et al* 1997; 1998; 2003; Feuerbach and Griffiths 1995; Herrmann and Kurbansakhatov 1994; Merkel 2013), Akhsiket (Papakhristu and Rehren 2002; Alipour *et al* 2011; Rehren and Papakhristu 2000) and Chāhak (Alipour and Rehren 2014). The evidence at Merv came from a deposit of an estimated 1250 crucibles and was interpreted as a permanent workshop, possibly run by a family (Feuerbach 2007, 321). The remains at Akhsiket were larger, consisting of thousands of crucible fragments attesting to production on an industrial scale (Papakhristu and Rehren 2002, 69). The material at Pap is said to be visually indistinguishable from those at Akhsiket (Rehren and Papachristou 2003, 397). The remains at Chāhak come from a 15m long and 15-40cm thick deposit along the side of road (Alipour and Rehren 2014, 244).

Although the Central Asian crucibles show some morphological variations, they share more common features than those from South Asia. Feuerbach (2002, 176-8; 2007), Alipour and Rehren (2014) and Rehren and Papachristou (2003) have already provided good morphological comparisons between crucibles of both regions, some of which will be reiterated here as well as other observations put forward by the author. The first consideration is the difference in shape. While most South Asian crucibles are cup, aubergine or conical in shape (chapter 2.4), those from Central Asia are long and cylindrical with a flat base. The lids of the Central Asian examples have one or two central perforations (with the exception of Chāhak) whereas most of the South Asian examples do not, or in the case of Mawalgaha (Sri Lanka), numerous very small perforations. Another consideration is the comparatively large size of the Central Asian crucibles. They are around 6-9cm in diameter and range in height from c.20cm at Merv to c.30cm at Akhsiket and Chāhak. Rehren and Papachristou (2003, 400) note that the South Asian examples hold only about one fifth of the volume of those in Central Asia.

The most striking difference however, lies in the manufacture of the crucible fabrics. Those in Central Asia are light grey to white in colour (dark grey at Chāhak) with a quartz and grog (at Merv only) temper. In contrast, the South Asian crucibles are all black in colour and tempered with charred rice husks. A trait that crucibles from both regions share, is the presence of a glassy slag on the interiors, usually in the form of a fin. Once again however, there is significant difference in these. The Central Asian crucibles, particularly the Akhsiket examples, have a much thicker layer of slag which is mostly green in colour, unlike the thin black coloured slag fins in South Asia. It is also important to mention a few other features of the Central Asian crucibles. The crucibles at Merv and Chāhak were placed on a refractory pad about 1-2cm thick (Feuerbach *et al* 1998, 41; 2003, 260) which as no parallels in South Asia. The Chāhak and Akhsiket crucibles also have a distinct woven textile pattern on their interior surfaces (Alipour and Rehren 2014, 244; Rehren and Papakhristu 2000, 56) suggesting that they were shaped around a textile fabric mould filled with sand (Papakhristu and Rehren 69-70; Alipour *et al* 2011, 17) or textile covered wooden template (Alipour and Rehren 2014, 254).

The numerous morphological differences between Central and South Asian crucibles, at the very least, suggest that these two regions represent two very distinct ceramic traditions

(Craddock 2003, 248; Rehren and Papachristou 2003, 403), if not completely different crucible steel manufacturing methods. Nevertheless, as with most South Asian sites, the carburisation process has been claimed for all Central Asian sites (Rehren and Papachristou 2003, 401). However, this is not without some debate. The process at Merv was first identified as co-fusion (Feuerbach *et al* 1997; 1998), then re-assessed as carburisation (Feuerbach 2002), but co-fusion has been pursued again more recently by Merkel (2013). The Akhsiket remains have undergone a similar review, first classified as glass production (Abdurazakov and Bezborodov 1966, 80-1), then re-assessed as crucible steel by carburisation (Rehren and Papakhristu 2000). It is proposed here, that even if the carburisation method is accepted for crucible production in both regions, the nature of the remains, particularly the difference in internal slag morphology, prove that this process must have been implemented differently. However, the nature of this process variation has yet to be determined.

It is important to mention that despite the numerous process re-interpretations in Central Asia, the theories proposed are always based on sound scientific data; analyses of crucible fabrics and internal slags, something that is often absent in the South Indian context (chapter 2.4). However, they also highlight the difficulty in identifying the manufacturing processes solely based on the scientific analysis of the materials. In the absence of an unused crucible charge, which would verify the original contents of the crucibles, the internal slag remains provide the most reliable chance of determining the methods employed. This is clearly recognised by the various authors that have made attempts at process identification in Central Asia (Feuerbach 2007; Merkel 2003; Rehren and Papakhristu 2000). Perhaps the most reliable method in finding some resolution on process variations in both regions would be to directly compare their crucible slag compositions. To date, no study has tackled this, probably in part due to the lack of scientific data from South Asia. A first attempt to compare crucible slags of both regions is an objective of this study (chapter 8.3.3).

Despite the very different technological approaches in both Central and South Asia, several authors have proposed a tenuous technological link between the two areas, mostly based on the shapes of the crucibles. Feuerbach (2007, 333) argues that the crucible steel process at Hyderabad (Telangana – referring to co-fusion) “was perhaps developed in Central Asia, and then Persians influenced the Indian production methods and techniques". She supports her arguments by stating that the shape and clay matrix of the crucibles are more closely related to those in Central Asia. She also refers to Bronson's (1986) identification of similarities between the Hyderabad co-fusion process, those mentioned by Islamic writers and Massalaski's account of production in Iran (Feuerbach 2007 332-3). The morphological similarities between all South Asian crucibles, as well as the clear differences to their Central Asian counterparts has already been discussed and will not be pursued further here. As to the co-fusion process in Telangana, several doubts as to the reliability of the evidence have been raised in chapter 2.2.3. As yet there is no archaeological evidence to support a co-fusion process in Telangana and Central Asia. Further work needs to be conducted in both areas to support the documentary accounts.

Another link has been proposed by Rehren and Papachristou (2003, 402). They argue that the crucibles in Sri Lanka have the same form and technological process as those from Merv/Akhsiket and are genealogically more similar to those in Central Asia than to the vessels in India. They suggest that the technology in Central Asia emerged from a single centre from whence crafts-people spread but arrived in Sri Lanka earlier (referring to the 6th to 10th centuries AD dated evidence from Sri Lanka) and transformed to match the different environmental and geological conditions. It is true that the later site of Mawalgaha dated to the 19th century AD has closer parallels to Central Asian examples only in that they are cylindrical and long in shape. However, the earlier remains at Hattota Amune have closer size and shape parallels with other South Indian sites such as Mel-siruvalur and the small type 2 crucibles from this study (to be discussed later). As discussed above, there can be no question as to the clear technological differences (in fabric, form and manufacture of the crucibles) between both regions, despite the possible similarity in both carburisation processes.

The purpose here is not to refute the idea that technological ties were shared by both regions but to highlight the tenuous nature of the evidence proposed. It is possible that the crucible steel technology diffused from a common origin and later adopted regional crucible forms and manufacturing processes, but there is insufficient evidence at this stage to establish it. Or conversely, argue against the multiple origins of crucible steel. There is some mention in historical texts as to the transfer of iron and steel from both regions. Al-Kindi for example, mentions the use of Sri Lankan (*Serendib*) steel in Iran, Yemen, Khorasan and Pakistan (see chapter 2.4.3), while both Tavernier (1679) and Voysey (1832) attest to wootz trade from Golconda (Telangana) to Persia (see Allan and Gilmour 2000, 113-22; Le Coze 2007). However, this only indicates the movement of the finished product (crucible steel), and nowhere is it mentioned or implied that there was a transfer of technological knowhow.

This is not helped by the lack of sturdy contextual or scientific dating for most South Indian sites, and further stresses the need for more archaeological studies, such as excavation of already known sites or wider investigative surveys to identify new ones. This would help to ascertain the longevity and widespread nature of this technology in the sub-continent and provide more concrete data on which to propose early origin theories and inter-regional connections. It is also worth noting, that no evidence for crucible steel manufacture to date has been found in the vast region of North India and Pakistan, which separates both regions by land. As the chronology of crucible production stands, the earliest evidence is in Sri Lanka (dated from the 6/7th century AD), then there are the Central Asian sites (dated from the 8/9th centuries AD) followed by the South Indian sites which can be dated by documentary evidence from the 17th century AD. Further work is required, to clarify this chronology and resolve some of the large gaps in dating evidence.

3 Physical, Cultural and Historical Setting

This chapter will outline in brief the physical, cultural and historical setting of the study area to provide some context for the location of past metallurgical activities and the survival of the remains. Very few recent publications have dealt with these themes (physical and cultural geography) in the Indian context and the author has had to rely on primary sources found online. In order to assure the reliability of the data obtained, only official government-operated websites have been used. The majority of the information has been acquired from government reports, statistics and censuses.

3.1 Physical Setting

3.1.1 Location

Telangana is the 29th state of India formed on the 2nd of June 2014 after its separation from the state of Andhra Pradesh. It is situated in the central-eastern stretch of the Indian Peninsula (South India – Figure 3.1). It covers 114,840 km^2 and is bordered by the state of Andhra Pradesh to the south, Karnataka to the west, Maharashtra to the north-west and Chhattisgarh and Odisha to the east. Telangana comprises 10 districts: from north to south and east to west there are Adilabad, Nizamabad, Karimnagar, Medak, Warangal, Ranga Reddy, Hyderabad, Nalgonda, Khammam and Mahabubnagar (Figure 3.1). The study area falls in the northern districts of Adilabad (19.6667° N, 78.5333° E), Nizamabad (18.6720° N, 78.0940° E), Karimnagar (18.4369° N, 79.1242°) and Warangal (18.0000° N, 79.5800° E) with the core area situated in northern Karimnagar. These districts fall north of the state capital Hyderabad (17.3700° N, 78.4800° E).

Figure 3.1 – Location of Telangana in relation to India and the location of its districts (research area encircled).

3.1.2 Landscape, Topography and Drainage

In order to gain a better understanding of the geographical setting of Telangana, one needs a brief introduction to its location within the wider sub-continent landscape. Peninsular India is dominated by the geomorphic sub-unit referred to as the Deccan Plateau which covers the majority of Central and South India. Geographically, this eastward sloping plateau is bound by mountain ranges to the west (Western Ghats) and east (Eastern Ghats) as well as the Nilgiri Hills to the south and Aravalli/Chota Nagpur Hills to the north (Kale 2014, 26;

Kale and Vaidyanadhan 2014, 73-4). Although there is much landscape diversity within the Deccan, two main types of terrain prevail. The northern and western parts are covered by the Deccan Traps, which formed some ~65 million years ago (late Cretaceous) when huge lava flows erupted as the sub-continent shifted from the old Gondwanaland continent to its present location in Eurasia (Kale and Vaidyanadhan 2014, 67-70). These lava flows (Deccan Traps) cover the whole of Maharashtra as well as some parts of Gujarat and Madhya Pradesh. The landscape in these areas is characterised by flat-topped, stepped hills separated by wide, open valleys (Kale and Vaidyanadhan 2014, 65). The southern and eastern parts of the Deccan on the other hand, are dominated by a granite-gneissic landscape characterised by undulating plains dotted with koppies, boulder inselbergs and bornhardts (Kale and Vaidyanadhan 2014, 65). This landscape dominates large parts of Karnataka, Andhra Pradesh and Telangana.

The Deccan Plateau comprises of several smaller plateaux or escarpments of differing heights. The Telangana region constitutes one of these smaller plateaux (Kale and Vaidyanadhan 2014, 73-4). It forms a peneplained part of the ancient Deccan block (Singh 1971, 824-5) sandwiched between the Deccan Traps to the west and Eastern Ghats to the east. Like much of the Deccan, Telangana owes its landscape and topography to extreme erosion and denudation of the surface rocks (Kale and Vaidyanadhan 2014, 74). The region of Telangana primarily consists of flat or gently undulating plains at an elevation of ~300-600m above sea level. This landscape is dotted with numerous isolated granitic outcrops or monadnocks of various sizes and shapes (Figure 3.2). These, also known as *Kondas* in the regional language, have played an important cultural role in the region. Many villages have been named after these imposing hills and in some cases they form the settings for temples (Singh 1971, 824-5). They also play an economic role by offering an array of mineral resources allowing past and present communities to thrive in the area. One commodity especially relevant to this study are the banded iron formations seen on many of the larger outcrops which enabled ancient iron and steel industries to flourish. Stone quarrying of these hills is also a common sight in the region. The peneplain's topography changes dramatically in the northern and western boundaries of the state where the lava surfaces of the Deccan Traps form larger flat topped hills that rise abruptly attaining heights of up to 800m above sea level (Singh 1971, 825).

Figure 3.2 - Rolling plains intersected by large hillocks, typical of Telangana's landscape (source: Pioneering Metallurgy Project 2010).

The landscape of Telangana is intersected by river and tributary graded valleys. The two largest riverine systems are the Godavari and Krishna which rise from the Western Ghats in Maharashtra roughly following the plateau's eastward tilt, to pour into the Bay of Bengal on the eastern coast (Singh 1971, 825). While the Krishna flows along the southern border between Telangana and Andhra Pradesh, the Godavari transects the study area, constituting the boundary between Adilabad and Karimnagar districts. It is the largest river in South India (1465km) originating near Nashik (Maharashtra) and flowing east where it enters Telangana at Basar (Adilabad district). It carries on flowing east but turns south-east in the eastern part of the state (vaguely following the border with Chhattisgarh) eventually entering Andhra Pradesh at Bhadrachalam and spilling into the sea at Yanam. Approximately 79% of the river's catchment area falls in Telangana, being fed by many tributaries such as the Manjira, Manneru, Pranahita, Indravati and Sabari (Singh 1971, 825). The river is mainly rain fed running almost dry for half of the year (Figure 3.3) until it is swelled by the monsoon rains from June to December.

This river is of importance to the study as it provides the majority of fresh water in northern Telangana enabling large expanses of land to be irrigated for agriculture as well as providing electricity through hydroelectric plants along its course. The landscape is littered with *bunds* and tanks (modern and ancient) serving as reservoirs for irrigation. In many of the older villages disused *bunds* can be seen as large parts of the region are now provisioned with water through a series of canal systems and wells. In antiquity the river may also have served as an important route for the movement of goods to port towns on the coast and enabled international trading. It is revered by Hindus and many settlements have sprouted along its banks.

Figure 3.3 - Godavari river in the months of February and March (end of winter season) running almost dry (source: Pioneering Metallurgy Project).

3.1.3 Geology and Mineral Resources

The state of Telangana has a unique geology that is host to a variety of mineral deposits. Although systematic work and research has been carried out (particularly by the Geological Survey of India - GSI) to map the geology and mineral resources of the region there is still scope for further detailed exploration of the area in order to identify more mineral deposits (Phani 2014, 15450). The separation of the state from Andhra Pradesh has spurred new interest in the mineral resources of Telangana, primarily for exploitation and mining (Andhra Pradesh State Mineral Policy 2013).

The geology of Telangana consists of various rock types of Archaean to Quaternary age (Phani 2014, 15451; GSI). Figure 3.4 below shows a generalised geological map of Telangana (GSI). The majority of Telangana state (central and south-west) is dominated by Peninsular Gneiss of Achaean to Proterozoic age. Of a similar age are large expanses of Closepet Granite situated in the western and south western part of the state (western Ranga Reddy and Mahabubnagar district) while in the northern part (on the Nizamabad and Adilabad district boundary) there is a small area of Undifferentiated Younger Granite. In the south eastern part of the state (south and east Khammam district) there are formations of the Eastern Ghats Supergroup, primarily Charnockite and Khondolite, but also some band formations of Alkali Complex (Figure 3.4).

The outskirts of the state offer a more varied geology where the Archaean basement is overlain by rocks of younger series (Singh 1971, 823-4). There is a long continuous belt of rock formations belonging to the Gondwana Group; primarily Kamthi, Malleri, Barakar and Kola formations stretching across the north eastern part of the state (eastern parts of Adilabad, Karimnagar, Warangal and Khammam districts along the Godavari trough). In addition, parallel to this belt in eastern Adilabad, Karimnagar and Warangal districts there are formations of the Penganga Group, Pakhal/Cuddapah Supergroup and Sullavai Sandstone. The northern boundaries of Adilabad and western boundaries of Nizamabad and Medak districts consist of the Deccan Traps where the geology is primarily Basalt with Intertrappeans. A small area in western Medak district also contains Laterite with Bauxite overlying the Deccan Traps (Figure 3.4).

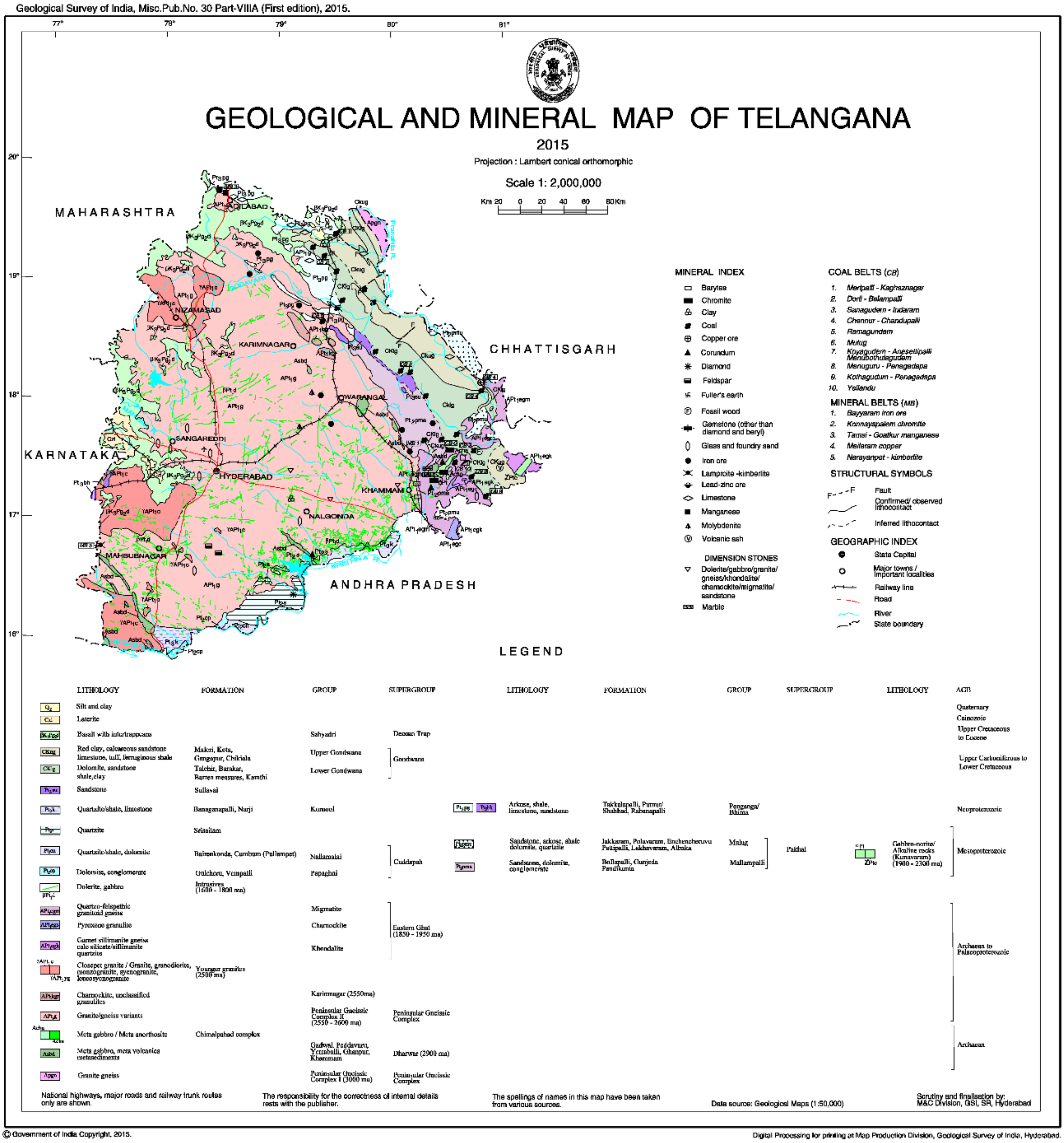


Figure 3.4 - Geological map of Telangana (Geological Survey of India 2015).

This varied geology offers a wide array of metallic and non-metallic mineral resources. The metallic minerals include chromite, copper, gold manganese, molybdenite, galena and iron ore. The non-metallic minerals include asbestos, amethysts, barytes, clays, a variety of building stones, coal, diamond, dolomite, feldspar, fullers earth, garnet, graphite, kyanite, limestone, mica, ochres, quartz, steatite, talc, zircon and radioactive minerals primarily uranium (Phani 2014, 15453-4; Department of Mines and Geology; Andhra Pradesh State Mineral Policy 2013; Telangana Statistical Year Book 2013, 113-6).

Those currently of major economic importance for the region are the coal and limestone mineral reserves (Telangana Statistical Year Book 2013, 113-6). Coal deposits are found in the Barakar rock formations forming part of the long Gondwana rock belt stretching across the north-eastern side of the state in parts of Adilabad, Karimnagar, Warangal and Khammam districts (Pahni 2014; Department of Mines and Geology; Johnson 1981, 5-6). Limestone deposits are widespread in the state. There are cement grade limestones found in Adilabad, Karimnagar and Nalgonda districts. In addition, limestones associated with the Bhima Group used for flooring slabs are found in Ranga Reddy district. Flux grade dolomitic limestone occurs in Khammam district. Limestones of the Kurnool Group in Manbubnagar district. Limestone of the Palnad group in Nalgonda district and limestones belonging to the Pakhal Supergroup and Sullavai Sandstones in Warangal district (Phani 2014, 15455-6; Singh 1971, 829-30; Department of Mines and Geology).

Many mining leases have been given throughout the state and of the four districts encompassing the study area, Adilabad is by far the most productive with 69 mining leases producing 32% of the state’s coal, 22% of the limestone, 27% of the clay and 15% of the manganese production (Department of Mines and Geology).

3.1.4 Iron ore

Iron ore deposits are an important resource found throughout the region. Although in modern times iron ore deposits are not as widely exploited as other minerals discussed above and equate to a very small percentage of the financial revenue of the state (Telangana Statistical Year Book 2013, 113-6), their presence is of significance to this study.

Three major types of iron ore are found in the region: hematite, banded-magnetite/hematite-quartzite and lateritic ores (GSI 2006, 27; Roonwal 2012).

The major iron ore deposits are found in Adilabad, Karimnagar, Warangal and Khammam districts (Figure 3.5). The deposits are associated with different rock formations throughout the area. In Adilabad, hematite iron ore occurs in the upper Gondwana rocks near Sirpur while isolated patches of banded-magnetite-quartzite occur near Chityal, Kallada, Dasturabad, Robanpalli, Lakshettipet and Utnoor (Pahni 2014, 15452; GSI 2006, 17-34). These deposits follow NW-SE trending banded iron formations and contain an estimated 16Mt of low grade ore (Pahni 2014, 15452; GSI 2006). In Karimnagar banded-ferruginous-quartzite occurs near Chandoli, Yerrabali, Kommegudem and Manal. The deposits at Chandoli are estimated at 15Mt of low grade ore while the deposits at Yerrabali at 0.68 million tonnes of iron ore with 60% Fe content (GSI 2006, 33). Smaller banded magnetite-quartzite deposits are also known from Amberpet, Arnakoda, Mallapur and Choppandandi (Department of Mines and Geology). In Warangal and Khammam, ores are associated with two different geological formations: hematite associated with the Pakhals and banded magnetite/hematite-quartzites of Dharwar age (Pahni 2014, 15452; GSI 2006; Roonwal 2012). Hematite iron ore is found in the Pakhal (Supergroup) rocks extending in a NW-SE direction adjacent to the Gondwana belt in the eastern part of the state. The main deposits are found near Cheruvapuram, Bayyaram, Opulapuram, Nilancha and Gopalpur. Those found near Bayyaram contain the most high grade hematite in the region with an estimated 7.96Mt (GSI 2006, 29-30; Roonwal 2012). The banded magnetite/hematite-quartzite deposits are associated with Dharwar (Supergroup) rock formations. Major occurrences are found near Utla, Tatraiyepalli, Motla Timmapur, and Gopalpur with a combined estimate of 40Mt of low grade ore present (GSI 2006, 31; Roonwal 2012). Due to the low grade nature of the iron ore deposits found in Telangana, very few of these are currently exploited.

Lateritic ores are associated with the Deccan traps situated in parts of Adilabad, Nizamabad, Medak and Ranga Reddy (GSI 2006; Department of Mines and Geology). These have high Fe and Al content but the proportions present of both elements are too high to be exploited for modern iron or aluminium production - too aluminous to be used as iron ore and too rich in iron to be used as aluminium ore (Department of Mines and Geology). No lateritic ores are presently mined for the production of iron but laterite is widely extracted in the state for use in the cement industry (Department of Mines and Geology). Lateritic ores were likely to have been exploited in the past for the production of iron on a smaller scale (Lowe 1995).

The iron ore deposits discussed above constitute the major iron reserves in Telangana state recognised in modern times but it is important to mention that many smaller banded magnetite/hematite outcrops were observed during the Pioneering Metallurgy Project fieldwork season in 2010. Although these may not be of economic value for present large scale iron production, they would have been exploited in the past for smaller scale production. Many isolated outcrops were noticed in Karimnagar, Adilabad and Warangal districts usually in parts of granitic hillocks scattered across the landscape.

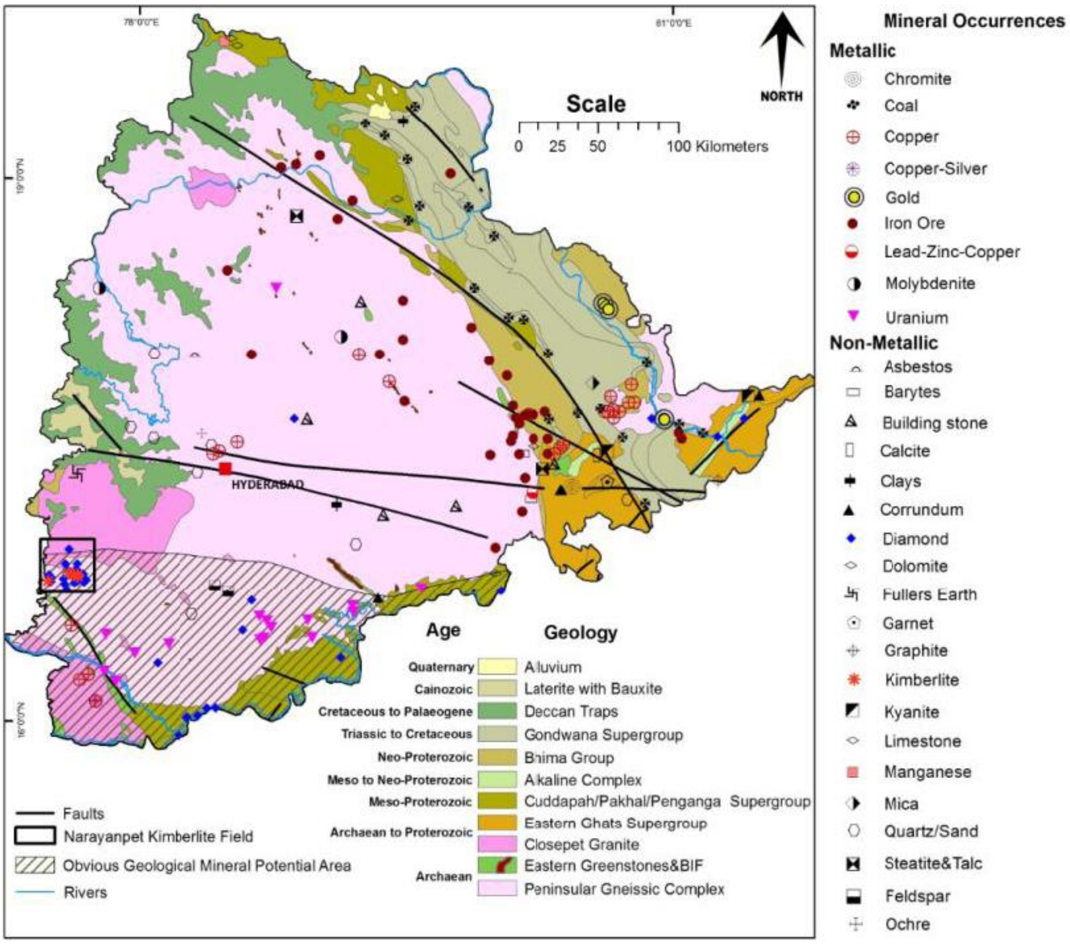


Figure 3.5 - Major geological group formations and mineral occurrences in Telangana (Pahni 2014, 15453).

3.1.5 Vegetation

The natural vegetation of Telangana state primarily consists of forests. Forests constitute 25% (29242 km^2) of the total state land area (Reddy, B.S. 2013a, 2). This extensive forest cover is unevenly distributed with the majority occurring in a wide band in the northern and eastern parts of the state (Bhavan 2010, 2; Singh 1971, 828-9). The majority of the forests are situated in Khammam (8437 km^2) and Adilabad (7232km^2) districts which contribute 25% and 29% respectively to the state's total forests (45-53% of their land area). Warangal (3710 km^2), Karimnagar (2545 km^2) and Nizamabad (1812 km^2) districts also have significant forest cover with 21-29% of their land area covered in forests, accounting for 28% of the forests in the state (Reddy, B.S. 2013a, 2). Figure 3.6 below shows the location and extent of forest cover in Telangana state. Forest cover is defined in density (vegetation volume to area) from dense (>8m^3/0.1ha), open (1-8m^3/0.1ha) to scrub (<1m^3/0.1ha) (Bhavan 2010, 13-7). Approximately 37% of the forests are dense while open and scrub forests account for 34% and 29% respectively (Reddy, B.S. 2013a, 30). The majority (72%) constitute of Reserved Forests while 26% fall under Protected Areas encompassing three national parks and seven wildlife sanctuaries (Reddy, B.S. 2013a, 8; Bhavan 2010, 2-3). The remaining 2% are un-classified forests.

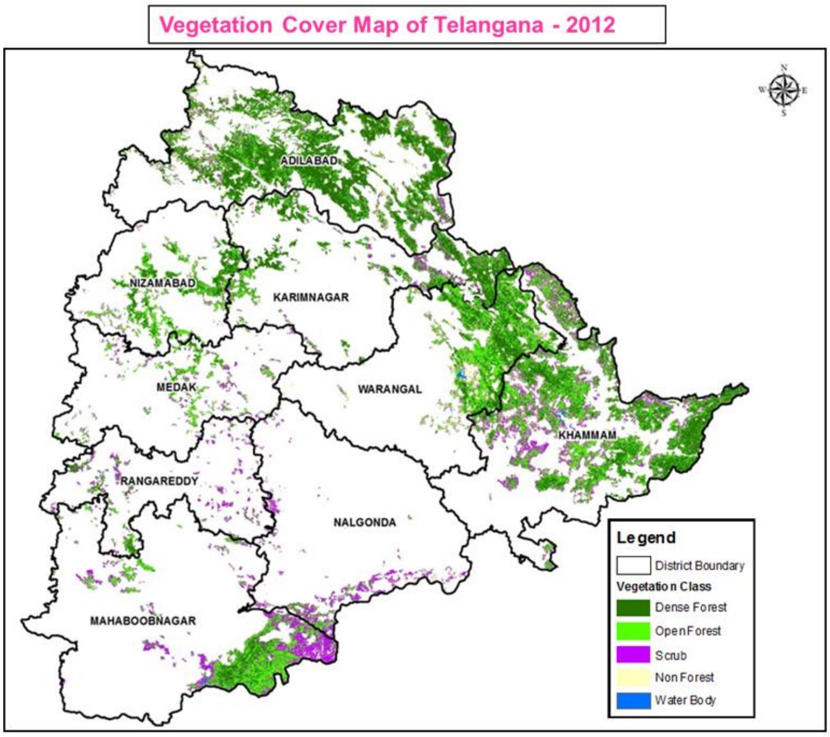


Figure 3.6 - Vegetation cover in Telangana state (Telangana Forest Department 2012).

The forests of Telangana constitute of three main types: tropical dry deciduous forest, tropical moist deciduous and tropical thorn forests (Bhavan 2010, 2; Reddy, B.S. 2013a, 1; 2013b, 6; Reddy *et al* 2007, 1; Singh 1971, 828-9).

Tropical dry deciduous forests (Figure 3.7) are the most abundant in the state accounting for over 80% of the forest cover (Reddy, B.S. 2013a, 1; 2013b, 6; Reddy *et al* 2007, 1). They grow where rainfall is relatively low at an altitude of 200-600m (Reddy *et al* 2007, 8; Singh 1971, 828-9). The predominant tree is teak (*Tectona grandis*) with a mixture of other species such as *Anogeissus latifolia*, *Terminalia alata*, *Diospyros melanoxylon*, *Lannea coromandelica*, *Xylia xylocarpa*, *Gardenia, Hardwickia binate* and *Chloroxylon swietenia* (Reddy *et al* 2007, 8; Singh 1971, 828-9).

Tropical moist deciduous forests account for less than 10% of the forest cover and occur where there is high annual rainfall >1000mm (Reddy, B.S. 2013a, 1; 2013b, 6; Reddy *et al* 2007, 1). The most common species are *Xylia xylocarpa*, *Terminalia alata*, *Protium serratum*, *Diospyros montana*, *Lannea coromandelica*, *Madhuca indica*, *Mallotus philippensis*, *Pterocarpus marsupium* and *Buchanania lanzan* (Reddy *et al* 2007, 8; Singh 1971, 828-9).

Tropical thorn forests also account for less than 10% of the forest cover and are usually degraded due to biotic interference and over exploitation (Reddy, B.S. 2013a, 1; 2013b, 6; Reddy *et al* 2007, 1). They are usually confined to the outer edges of hill slopes and grow in areas with low rainfall and high temperatures; primarily in the southern districts of Telangana (Reddy *et al* 2007, 9; Singh 1971, 828-9). Common species in this type are *Acacia chundra-leucophloea*, *Albizia amara*, *Catunaregum spinosa*, *Canthium parviflorum*, *Mimosa hamata*, *Prosopis spicigera-juliflora* and *Acacia caesia* (Reddy *et al* 2007, 9; Singh 1971, 828).

Figure 3.7 - Teak dominated forests found in the Telangana region (source: Pioneering Metallurgy Project 2010).

3.1.6 Climate

The climate of the region and indeed that of India is of crucial importance to the economy and the sustainment of life. “Nowhere else are so many people so intimately dependent upon rainfall rhythms; the whole prosperity of India is tied up with the eccentricities of its seasonal winds” (Sukhwal 1971, 25). In addition to being of significance today, the region’s climate would have been important to people in the past perhaps dictating (in part) their way of life and giving rise to certain seasonal activities which may be reflected in the archaeological record. Water as rainfall is probably the most precious commodity, enabling the support of a large population by providing irrigation for agricultural fields, power through hydroelectric plants as well as the everyday consumption needs of the populace (Attri and Tyagi 2010, 1; Johnson 1979, 48).

The state of Telangana like many parts of India has a climate dictated by the monsoonal rhythm (Attri and Tyagi 2010; Singh 1971, 825-6; Spate 1954, 40-60; Department of Agriculture and Cooperation). Four main seasons are recognised:

1. **January to February – Cold (Winter) Period**

The cold weather period after the cessation of the north-east monsoon is the driest of the year with an average of 11mm of rainfall over the Telangana Region. The northern districts of Adilabad, Karimnagar, Nizmabad and Khammam get the most rain in the state with 15.1 to 17.4mm of mean rainfall whereas other districts get <10mm (Telangana Statistical Year Book 2013, 61-6). The winter period is also the coldest with temperatures in the four districts encompassing the study area averaging (mean) between 20-25^{o}C with a mean minimum of 13^{o}C and a maximum of 32^{o}C. The temperature rarely falls below 15^{o}C during this period and does not rise above 35^{o}C until the start of the warmer period in March (Johnson 1981, 17-29; Singh 1971, 825-7; Telangana Statistical Year Book 2013, 61-6). The sky mostly remains calm and clear and the air is relatively low in humidity with light northerly winds (Attri and Tyagi 2010, 2-3; Singh 1971, 825-7; Spate 1954, 41-2; Telangana Statistical Year Book 2013, 61-6).

2. March to May – Hot (Summer) Period

After the cold period where the temperatures steadily rise through January and February, the hot weather period starts in March with a sharp rise in the mean daily temperature at 27-29°C. The temperatures continue to rise, peaking in the month of May with a mean temperature for the northern districts of 33-35°C. Throughout this hot period the temperatures rarely go below 19°C (minimum mean temperature in March) and above 42°C (maximum mean temperature in May). These hot months are also relatively dry with an average mean of 50.79mm of rainfall in Telangana state. Both Warangal and Khammam districts receive the most rainfall in this period with a mean of 63.3mm and 86.7mm respectively (Singh 1971, 825-7; Telangana Statistical Year Book 2013, 61-6). The sky in this hot period also remains calm and clear and the high temperatures are not abated by the prevalent hot winds making the season uncomfortable. However, the heat is occasionally repressed by local thunder showers in April and May (Attri and Tyagi 2010, 3-4; Singh 1971, 827; Spate 1954, 42).

3. June to September – South-West Monsoon

The south-west monsoon season starts around the second week of June where sudden outbursts of clouds and south-westerly winds coming from the Arabian Sea bring heavy rains (Singh 1971, 825-7; Spate 1954, 43-6; Department of Agriculture and Cooperation). This change in weather reduces the mean temperature of the northern districts by about 3-4°C to 29-32°C. The temperature decreases further in July and remains reasonably constant through August and September at a mean average of around 26-28°C. During these months the area has minimum mean temperatures of 22-24°C and maximum mean temperatures of 31-32°C (Singh 1971, 825-7; Telangana Statistical Year Book 2013, 61-6). However, the welcome decrease in temperature is also marked by an increase in humidity (above 80% in some areas) not permitting the weather to remain comfortable (Attri and Tyagi 2010, 4-5; Singh 1971, 825-7; Spate 1954, 43-6; Department of Agriculture and Cooperation). The monsoon brings the wettest season of the year with an average of 715mm of rainfall in Telangana state accounting for approximately 79% of the total annual rainfall. The intensity of rainfall escalates throughout June and July to reach its peak in August. The northern districts of Adilabad, Karimnagar, Nizamabad, Warangal and Khammam get the most rainfall in this season with 799-984.1mm whereas the other districts get <676mm (Singh 1971, 825-7; Telangana Statistical Year Book 2013, 61-6).

4. **October to December – North-East Monsoon**

In the middle of October the south-westerly winds are replaced by the north-eastern monsoon coming from the Bay of Bengal (Attri and Tyagi 2010, 5; Singh 1971, 825-7; Department of Agriculture and Cooperation). The transition of the monsoon seasons is marked by reasonably stable weather conditions and a small temperature increase in early to mid-October but these fall considerably by November with an average temperature around 23^{o}C. The mercury falls even further into December which marks the start of the cold weather period by being the coldest month of the year with temperatures averaging 20-22^{o}C. The minimum mean temperature is 13^{o}C and maximum mean temperature is 30^{o}C for the last two months of the year (Singh 1971, 825-7; Telangana Statistical Year Book 2013, 61-6). The rains brought by the monsoon produce on average 129mm of rainfall throughout the state of Telangana (approximately 14% of the annual rainfall) with the highest rainfall seen in the southern districts of Nalgonda and Hyderabad (Singh 1971, 825-7; Telangana Statistical Year Book 2013, 61-6). Although some rains occur there is a decrease in humidity with clearer skies throughout most of this season (Attri and Tyagi 2010, 5).

The state of Telangana normally receives on average 906.54mm of rain annually with the greatest concentrations in the northern districts of Adilabad, Karimnagar, Nizamabad, Warangal and Khammam with 970.3-1157.4mm (Telangana Statistical Year Book 2013, 61-6). Although there is little variation in yearly rainfall and temperatures from the normal climatic conditions, the area is prone to periods of drought approximately every 6-10 years, therefore semi-arid conditions prevail (Attri and Tyagi 2010, 91; Singh 1971, 827; Department of Agriculture and Cooperation). Severe flooding during the south-west monsoon is also common and can cause serious damage to agricultural land, crops and settlements, sometimes forcing people to be displaced.

3.2 Cultural Setting (Recent)

3.2.1 Demography

Setting out a brief population demographic is important as the number of people inhabiting the region as a direct impact on its economy, ecology and ultimately the preservation of archaeological remains. The data provided in this section have been obtained from the 2011 Indian Census (Anuradha 2011a; 2011b; Census of India 2011) and the Telangana state online portal.

According to the 2011 census it has a population of 35,286,757 with the south eastern districts of Hyderabad, Ranga Reddy and Mahbubnagar being the most populated (with 4-5.3 million in each district). The other districts have somewhat lower populations varying from 2.6-3.8 million. In terms of population densities the state has an average of 307 people per km^2. Hyderabad is by far the most densely populated with 18480 people per km^2, followed by Ranga Reddy with 707 people per km^2. The remaining districts have much lower population densities between 170-322 people per km^2. The state has a female to male ratio of 988 per 1000. Of importance is the fact that the majority of the population (61.33%) are rural based as opposed to the urban population which accounts for 38.64%. This is especially marked in the districts furthest away from Hyderabad where urbanisation is as low as 15% (in Khammam) with most districts having between 23% and 28% of their population living in urban centres. The area also has a large population of Scheduled Caste and Tribes numbering close to 9 million people.

3.2.2 Land Use – Industry and Agriculture

A brief account of Telangana's industry and land use will be outlined here. All population data was retrieved from Census of India 2011 while all industrial, agricultural and land use data was retrieved from Telangana Statistical Year Book 2013.

Telangana is home to many industries with over 19000 registered factories as of 2011. The majority of these are based in Ranga Reddy where nearly 6000 factories are registered while Adilabad as the fewest with less than 700. The other districts have between 1200 and 2300 registered factories (Telangana Statistical Year Book 2013, 112). The major contributors to the region's economy are industries relating to the production of food, beverages, textiles/clothing, paper, chemicals, pharmaceuticals, rubber, glass, iron/steel, electric motors and machinery. Mining is also economically significant but employs very few people compared to the other industries mentioned above (Telangana Statistical Year Book 2013, 107-12). In addition, a significant proportion of the region's industries are household based, employing around 5% of the main working population (Census of India 2011). The majority of household industries are found in Adilabad, Nizamabad and Karimnagar where more than half of the people working in household industries reside.

Although there has been a sharp increase in industries over the past few decades, agriculture still forms the backbone of the economy, employing 55% of the main working population (Census of India 2011; Telangana Statistical Year Book 2013, 67-84) and accounting for approximately 30% of the regions income (Pingle 2011, 128). As can be expected with its 100% urban population, Hyderabad employs the least people for agriculture which account for <3% of its working population. This is followed by Ranga Reddy with 28% while the other districts have between 57-72% of their populations employed in agriculture. The agriculture industry takes up the most land use with the net sown area using approximately 41% (4653950 ha) of the land as well as 3% reserved for permanent pastures/grazing and an additional 1% for miscellaneous tree crops and groves. This is in stark contrast to land used for non-agricultural uses (8%) and areas left fallow (17%). The remainder of the land (30%) is taken by forests, water bodies and other non-cultivatable land (Telangana Statistical Year Book 2013, 69). Approximately 58% of the produce grown in the state are food crops while 42% are non-food crops. Many different crops are grown in Telangana. The most important are cereals (rice, jawar and maize), pulses (green gram, red gram and bengal gram), oil seeds (groundnut, soyabean and castor) as well as chillies, turmeric, sugarcane, mangoes and cotton (Telangana Statistical Year Book 2013, 70-6). By total area grown and tonnage of goods produced, rice and cotton are by far the most significant crops (Figure 3.8). Approximately 21% of the total area cultivated is rice while cotton accounts for 31%. More cotton (by area) is grown in Adilabad than any other district while rice is dominant in Nizamabad and Karimnagar (Telangana Statistical Year Book 2013, 76-7).

Figure 3.8 - Agricultural exploitations in Telangana. Rice paddy fields above and cotton fields below (source: Pioneering Metallurgy Project 2010).

Irrigation forms an important part of the agricultural economy. Large reservoir earthworks such as *bunds* are a common sight in the region. Some of these are ancient and suggestive of large populations inhabiting the area in the past. Past and present irrigation forms leave their mark on the landscape. As of 2013 approximately 38% of the cultivated land is irrigated through non-natural means (Telangana Statistical Year Book 2013, 86). This is a marked increase from the 17.5% of agricultural land irrigated in 1971 (Singh 1971, 843; Vakulabharanam 2004, 1424). The main irrigation methods are through tanks (Figure 3.9), canals, tube wells and dug wells (Figure 3.9). The most common method are tube wells which account for 55% of the irrigated land followed by dry wells at 29%, tanks at 9%, canals at 5% and other methods at 2% (Telangana Statistical Year Book 2013, 86). The repartition of irrigation methods is not uniform across the state. Tanks irrigate more land in Warangal and Khammam, canals in Mahbubnagar and Khammam, tube wells dominate the irrigation in Mahbubnagar, Medak, Nizamabad and Nalgonda while dug wells are dominant in

Karimnagar and Warangal (Telangana Statistical Year Book 2013, 86). Of importance is the fact that over the last few decades there has been shift from tank dominated irrigation to tube wells. This is marked by the 1956 statistics when 66% of the irrigation came from tanks (Pingle 2011, 124).

Figure 3.9 - The most common irrigation methods in Telangana. A water tank on the left and a dug well on the right (source: Pioneering Metallurgy Project 2010).

3.2.3 Settlements and Infrastructure

Although there has been a considerable increase in urbanisation, the majority of the population still resides in rural areas. The countryside is dotted with many village communities. According to the 2011 Census of India there are 10128 inhabited villages in Telangana. The majority of these are small and compact. Many factors have determined their location, like the availability of cultivable land, transport routes (major roads), availability of fresh water for consumption and irrigation as well as the general landscape and topography (Singh 1971, 834-5). For this reason larger settlements have sprouted along major roads and river-ways (or tanks).

Most villages have one major road running through the centre with minor lanes branching off from this main artery. In some cases there are also a few transverse roads connecting these lanes. Some minor roads end within the settlements but the more important ones lead to agricultural fields, water bodies or neighbouring villages (Singh 1971, 835-7). The houses are usually grouped into small blocks demarked by lanes with the largest house blocks concentrating in the core of the villages, gradually decreasing in size towards the outskirts. Village houses differ in build and size, usually dependant on the social status and wealth of the inhabitants. In older settlements, people in the upper echelons of society (land owners) usually have larger brick or stone-built houses located centrally in the village (Figure 3.10). People lower in status (artisans like potters, carpenters and smiths as well as labourers and herders) often concentrate in small groups on the outskirts of the villages, living in mud/wood-walled houses with thatched roofs (Singh 1971, 836-7 – Figure 3.10). In the last couple of decades, cement has overtaken more traditional forms of house building and flat roofed, one to three storey cement buildings are now a common sight in many of the larger and wealthier rural settlements (Figure 3.10). Shops and businesses have also sprouted along the major roadways. These often constitute of small, one storey, garage-looking cement buildings, linearly aligned along the roads (Figure 3.10). They provide the needs of the local population as well as serving those of neighbouring smaller settlements.

Figure 3.10 - Typical villages in Telangana. Larger brick built house compounds top left, mud/wood-walled house common on outskirts of villages top right, a modern cement house in construction bottom left and modern garage-like shops bottom right (source: Pioneering Metallurgy Project 2010).

In addition to the numerous villages, there are larger urban centres. According to the 2011 Census of India there are a total of 158 towns in Telangana. Some of these were important ancient fortified towns like Warangal which have grown into busy commercial centres (Singh 1971, 838-9). The locations of these towns were determined by the same factors (communication routes and water) as the larger villages but their continued expansion in recent years can be attributed to their favourable positioning along major road crossings and railway tracks (Singh 1971, 838-9). Each district has a headquarter town or city of the same name. The only exception is Ranga Reddy district where the headquarters are based in Vikaranad. The city of Hyderabad forms the administrative capital of the state and is one of the fastest growing cities in Asia, almost doubling in population from 2001 to 2011 (Census of India 2011).

The importance of infrastructure in terms of good road networks is crucial in the development of the region. Many of the region's roads are still not metalled making transportation of goods and people harder, especially in the most rural areas where dirt tracks are the only means of communication in and out of small villages. There are approximately 89758kms of roads in Telangana of which 29141kms (32%) are not tarmacked or metalled. This is especially marked in Adilabad and Karimnagar where almost half of the roads are un-metalled (Telangana Statistical Year Book 2013, 124-6). The roads consist of national highways, public works departmental roads (PWD) and Panchayat Raj roads. Whereas Hyderabad and its surroundings are served with good road networks, the rest of the state has a less well developed road system. The national highways no 7, 9 and 202 provide good links from Hyderabad to Nizamabad, Adilabad, Warangal and Mahbubnagar while the other major centres are served by other major roads (state highways). The areas in between, including large parts of Adilabad and Karimnagar remain somewhat deprived of good road networks. The rail networks almost mirror the national highway road network with all of Telangana's district headquarters served by rail from the focal point of Hyderabad. However, once again the areas in between the major urban centres are not accessible by rail.

3.2.4 Significant Recent Changes

The area known today as the state of Telangana has changed dramatically over the last few decades. The population as more than doubled since the 1971 census and more than quadrupled from the 1901 census (Census of India). This extreme population increase has had economic and ecologic knock on effects. The increased pressure of housing, feeding and financing such a growing population means that the construction, industrial and agricultural activities have also grown. Telangana's agriculture has seen a marked exponential growth rate of 3.6% from 1970 to 2001 (Vakulabharanam 2004, 1422) and an average growth of 13% total factor productivity every decade since 1956 (Reddy, A.A. 2011). In addition, since the Backward Regions Grant Fund (2009–10) census showed Telangana to be one of the most underdeveloped parts of India, a greater emphasis has been placed in developing the area. In the last decade or so, many roads have been tarmacked and the road networks around major urban centres improved (e.g. the recently built Hyderabad-Karimnagar state highway), facilitating movement and transport to the area. Fallow or unused lands have been converted for agricultural use sometimes significantly altering the landscape (flattening small hillocks, etc.). This is of importance to the study as many of the concerned archaeological sites border roads, villages and agricultural fields and these are now being destroyed to leave way for the expansion of the agricultural industry and settlements (chapter 5). Indeed, during the 2010 Pioneering Metallurgy Project survey many sites visited were in the process of being destroyed (flattened or removed). In some instances sites had been totally levelled only days prior to visiting them. The nature of the sites of interest to this study, primarily consisting of metallurgical waste such as slag, is that this material makes very adequate road ballast and in some cases local roads appear to have been made with ancient slags.

Being one of the poorest parts of India means that this area has to some extent remained undeveloped allowing many waste heaps associated with ancient metallurgical technologies to survive. However, the drive to economic development in the past few decades has somewhat changed these dynamics, often to the detriment of the regions rich archaeological heritage. The study's importance lies here, as this may be the last available chance to undertake detailed analyses of the ancient metallurgical residues of the region, before they disappear.

3.3 Historical Setting

This section sketches a general historical background of southern India as it relates to Telangana and the study area. Unlike North India, which has a wealth of early historical documentation, our understanding of the early history of South India is far less coherent (Sastri 1975, 2). Whereas North India was home to large and complex societies, with written records, South India (the area lying south of the Vindhya range of hills), is often projected as being less socio-economically advanced and divided by more 'primitive' tribal groups or kingdoms (Prasad, D. 1988, 6-7; Sastri 1975, 2) until movements of people from the North moved South during the Iron Age and Early Historic period. Because of this, the history of South India has traditionally been marginalised, as is evidenced by the many history books available on the subject which primarily focus on the seemingly more interesting (or at least better documented) developments in the North (Jha 2004; Stein 2001; Thapar 2002). Recent historical and archaeological research has begun to shed more light on the South but the knowledge gap, especially for the earlier periods, between North and South has yet to be bridged (Sastri 1975, 1-2). Telangana, as mentioned in chapter 3.1 above, is part of this southern territory.

This section will not deal with the complexities of Indian history but will serve as a guide to the broad historical periods and dynasties which have shaped the region. Where possible archaeological sites and evidence close to and within the study area will be highlighted. The aim is to provide some historical context for the development of the metallurgical technologies under study.

3.3.1 Neolithic to Iron Age (up to c. 500 BCE)

The majority of the Neolithic settlements in the South are found south of the Krishna River in modern day Andhra Pradesh (many in Guntur district), but several sites have been identified in the area of study, primarily along the banks of the Maneru River (Thogarrai, Kadambapur, Peddabankur) and Peddavagh River (Budigapalli, Polakonda, Devrapalli, Kolakonda) in Karimnagar district but also in Adilabad district (Utnur) (Sarma 2003, 89-90). The settlements seem to be on top of granitoid hills or elevated terraces on hillsides and valley floors but evidence for the types of structures built in the earlier parts of the Neolithic remain sparse. These become more discernible later in the Neolithic where there is evidence for circular wattle and daub huts with mud-plastered floors (Sarma 2003, 91-2). Archaeobotanical evidence indicates that millet and pulses were the main cultivated crops, dependent on rain-fed and gravity flow irrigation (Sarma 2003, 91-2). Animal husbandry was also economically important with domesticated cattle being predominant and to a lesser extent buffalo, sheep, goat and pigs (Sarma 2003, 92-3).

The Iron Age (c. 3100-2500 BP) succeeded the Neolithic-Chalcolithic and saw important socio-economic-cultural changes which provided the foundations for the dynasties of the Early Historic Period (Sastry, V.V.K. 2003, 107; Venkatasubbaiah 2014, 179). Villages began to form part of more urbanised complexes with market economies and there were significant developments in irrigation agriculture, funerary practices and technology (Sastry, V.V.K. 2003, 107). This period is characterised by the abundant 'megalith' burials scattered all over the south of India which gave rise to the term Megalithic Culture (Chakrabarti 1999, 238-9; Sastry, V.V.K. 2003, 107). These burials are different from practices in earlier periods as they are surrounded by large stones and some sites have more than 500 burials. Many types and variations have been identified (Sastry, V.V.K. 2003, 108) and a few are even unique to the region of study (Rao, K.P. 2014, 172-8). Of significance, is the presence of the first iron artefacts commonly found as grave goods (Sastry, V.V.K. 2003, 134). The origins of iron technology in India is still fiercely debated (chapter 2.1) and cannot be addressed here in detail. However, iron technology must have had a significant impact on the socio-economic activities of the region in this period (Venkatasubbaiah 2014, 179). The artefacts recovered from these burials are often common domestic and agricultural tools such as axes, knives, chisels, mattocks, sickles and ploughshares but also items which could have been used as weapons such as daggers, swords, spearheads and arrowheads (Sastry, V.V.K. 2003, 134; Venkatasubbaiah 2014, 194).

Archaeological investigations in the area of study have enabled the identification of many megalith burial sites and some habitation sites dated to this period. These are found in all districts in Telangana (Sastry, V.V.K. 2003, 109-22; Venkatasubbaiah 2014) especially within the Godavari and Krishna drainage systems. The habitation sites are mostly situated close to tributaries and streams while the burial sites are often further away from water sources, situated in rocky high-grounds in proximity to hillocks. Some sites have both habitation and burial components and these also seem to be located near water sources but also in proximity to hillocks. This is presumed to be due to the availability of the raw material (primarily granitic gneiss) used for the monuments (Sastry, V.V.K. 2003, 109; Venkatasubbaiah 2014, 182). The main sites in the area of study are Peddabankur, Kadambapur, Singapur and Mallangur in Karimnagar district; Pochampadu, Armur, Mahur, Yellareddipet in Nizamabad district and Kolakonda, Polakonda, Dornakal, Mungapet, Gangasanipalli, Tummanaali, Chinna Totturr in Warangal district (Sastry, V.V.K. 2003 111-22; Venkatasubbaiah 2014, 182-4).

3.3.2 Early Historic (c. 500 BCE – AD 600)

The start of the early historic period in Telangana is believed to have been marked by the expansion southwards of the Mauryan Empire (c. 321-180 BCE). Very little is known before the Mauryans as few historical texts have recorded earlier events. The few that do are rarely contemporary and dramatized within legends, causing problems for historians to make discernible sense of the people, events and even timescale (Sastri 1975, 61-73). "Until about 600 BCE works composed in the North exhibit little knowledge of India south of the Vindhyas, but acquaintance increased with the progress of the centuries" (Sastri 1975, 61). The main sources (the legends from the Mahabharata and Ramayana, Puranas and Epics) suggest that there had been movement of people between North and South from a relatively early age (Prasad, D. 1988, 6-7; Sastri 1975, 61-73). This movement, or 'Aryanisation', of the South, appears to have been gradual and peaceful, starting sometime around 1000BCE (Prasad, D. 1988, 6-7; Sastri 1975, 63) and completed sometime before the Mauryan Empire (Sastri 1975, 69). These people would have brought new ideas and beliefs to this land and although little is known of them, historical sources suggest that at least by the time of the Mauryans, the South was home to organised societies and kingdoms (Sastri 1975, 61-73).

The Mauryan historical sources are more numerous and varied providing a better account of the events and life of the people (Thapar 2002, 175). These include early historical texts such as the Buddhist and Jaina traditions, the early Dharmashastra texts, the Arthashastra of Kautilya and the Greek account *Indika* by Megasthenes. In addition, there is archaeological evidence in the form of Ashokan inscriptions (Jha 2004, 96; Thapar 2002, 176-84; Sastri

1975, 74-82) which shed more light on this empire which at its height covered the entirety of India (except the extreme south) as well as modern day Pakistan and Afghanistan. The exact southern extent of the Mauryan Empire is hard to determine but Ashokan inscriptions were found in the Raichur and Chitaldrug districts of Karnataka and the Kurnool district of Andhra Pradesh, suggesting that the Empire may have stretched that far south (Sastri 1975, 78) and hence encompassed the area of study.

The Mauryan Empire was well organised but in order to occupy such a large land area, a large army had to be maintained. Some accounts suggest a strength of up to 600,000 men (Jha 2004, 100; Thapar 2002, 191). State funds had to be increased and the Mauryans did so in various ways. One was to expand agriculture and bring new land under the plough. Many people were often moved from over-populated areas to ones that were less so and new settlements were built bringing an unprecedented expansion in settled agriculture, in many cases under the direct control of the state (Jha 2004, 100-2). Improved communications were important and road systems were built between larger settlements all over the Empire with routes now connecting the South of India to the North (Jha 2004, 102). Taxation was an important source of income and a system of land tax (bhaga) was set up whereby cultivators had to give a certain percentage of their produce to the state. Commercial activities (artisans) were also taxed and customs or ferry charges became an important source of revenue (Jha 2004, 103; Thapar 2002, 187-8). Of importance was also the state monopoly of mining and metallurgy. Mining (all mineral resources) and metal production (ferrous, non-ferrous and precious) was controlled by the state giving it exclusive control over the manufacture of weaponry, tools and implements needed for agriculture and industry (Jha 2004, 104-5).

After the death of Ashoka c. 232 BCE the empire fell into decline. Ashoka has often been blamed for this, in part due to his pro-Buddhist policy which may have antagonised the brahmanas, as well as his non-violence stance which weakened the army, opening the empire to threats. Causes for decline are likely to have been a combination of many factors, but a deciding factor appears to have been economic, whereby it became increasingly hard to maintain the system of governance of such a vast empire, invariably leading to the depletion of the state treasury. This is supported by the finds of debased silver coins dated to the later parts of Mauryan rule (Jha 2004, 114-6; Thapar 2002, 204-8).

The weakening of the Mauryan hold over their empire saw the rise of many smaller kingdoms and dynasties. The Satavahanas (c. 230 BCE – AD 224) were one of these and rose to prominence in the late third to early second century BCE to encompass most of central and south India at the height of their power, becoming the first major dynasty of the South (Sastri 1975, 83). Their ancestors had been employed in the service of the Mauryan Empire who then set up their own state after its decline (Sastri 1975, 83). Historical texts (the Puranas) suggest a reign of up to 30 kings over a period of around four and half centuries but they are often contradictory and do not satisfactorily resolve the absolute chronology nor indeed a specific start date (Babu 1999, 8-9; Deo 1999, 81-8; Sastri 1975, 83-4; Rao, P.R. 1994, 8-9; Shastri 1999, 9-19). This has led many historians to debate the origins of the Satavahanas, resulting in a divide between two main schools of thought. One group suggests the Western Deccan (Maharashtra) as the origin, while another the East (Andhra Pradesh), with no clear resolution to date (Babu 1999, 10-2; Jha 2004, 124; Rao, P.R. 1994, 4-8; Shastri 1999, 3-8).

The origin of the Satavahanas is of little importance to this study but the fact that they ruled over Telangana is relevant. As well as literary sources, the Satavahanas left numerous archaeological remains of which inscriptions, coins and settlements have been identified to this period (Sastri 1975, 84-5). In Telangana many settlement sites have been discovered. A few of the major ones are Bharatmunipetapadu, Kasipet, Rebbaladevapalli, Rayapatnam, Kolakonda, Kotilingala and Peddabankur in Karimnagar district; Vadaluru in Nizamabad district and Polakonda in Warangal district (Babu 1999, 20-63). Many of these have been excavated and some are located within the core research area of this study. One such settlement is Kotilingala. Located on the right bank of the Godavari River, it consists of a modern village built on top of a small mound c. 50 hectares in size and 6m in height (Babu 1999, 41-2; Murthy 2006; Singh, H.N. 1999, 428). There are remains of mud walls with gates and watch towers enclosing an area of over 1000m long and 300m wide. Finds included coins of King Satakarni, from the 2nd century BCE and inscriptions from the 1st century AD (Babu 1999, 41-2; Murthy 2006). The remains and artefactual evidence suggests that it had been a commercially important fortified town in the Satavahana period (Babu 1999, 41-2; Singh, H.N. 1999, 428).

Although Buddhism flourished during the Satavahana period with the building or enlarging of Buddhist stupas (like at Amaravati on the left bank of the Krishna River), most of the rulers were devoted to Brahminism with some even performing Vedic sacrifices to cement their reign (Rao, P.R. 1994, 17-9; Sastri 1975, 88-9). In society, new sub-castes were formed primarily based on people's occupation and foreigners appear to have been assimilated within this system (Sastri 1975, 87). Trade also flourished with many ports like Broach, Sopora and Kalyan gaining importance on both western and eastern coasts (Rao, P.R. 1994, 16-7; Rao, K.P. 1999), while larger inland settlements like Nashik, Govardhana, Kalyana and Srikakulam grew and benefited from this trade (Rao, P.R. 1994, 16-7). There was also a significant growth in trade with the western world (Arabic and Roman) in this period (Jha 2004, 129-32). The main waterways (the Godavari and Krishna) formed the main routes of communication and transport resulting in many towns springing up along their banks (Rao, P.R. 1994, 21). Another development is the organisation of traders into guilds (Sastri 1975, 88).

The Satavahanas never took imperial titles and unlike the centralised administrative system of the Mauryas, they distributed power throughout a hierarchy of officials. The territory was divided into small provinces governed by civil and military officials of whom some were even allowed to mint their own coins and marry into the royal family (Rao, P.R. 1994, 15-6; Sastri 1975, 87; Thapar 1999, 227-8). During the Satavahana decline in the 3rd century AD many of these local governors and feudatories established themselves as independent rulers (Jha 2004, 125; Rao, P.R. 1994, 15; Thapar 1999, 228), dividing Satavahana territory and starting a 300 year period of local kingdoms and minor dynasties. Those of prominence were the Abhiras in the north-west Deccan, the Chutus in Maharashtra and Kuntala, Pallavas in the south-east and the Ikshvakus in modern day Andhra Pradesh (Jha 2004, 125; Sastri 1975, 89).

3.3.3 Early Medieval (c. AD 600 – 1000)

From the power struggles of minor dynasties and local kingdoms in the later parts of the southern Early Historic period, the Western Chalukyas of Badami (c. AD 543 - 752) gained control of the north-western Deccan, marking the start of the early Medieval period. The founder was Pulakesin I who fortified Badami in Northern Karnataka around AD 543

(Murthy, S.S.R. 2009a, 16-7; Rao, P.R. 1994, 37; Sastri 1975, 134). Under Pulakesin II the dynasty expanded into the Eastern Deccan, subduing the local kingdoms of Kosala, Kalinga, Pishtapura and the Vishnukindins, bringing most of present day Telangana and Andhra Pradesh into his dominion (Murthy, S.S.R. 2009a, 19-22; Rao, P.R. 1994, 37; Sastri 1975, 135). Around AD 624 he appointed his brother, Vishnuvardhana, as viceroy of the Andhra country and with the permission of Pulakesin II, Vishnuvardhana founded a dynasty of his own (Murthy, S.S.R. 2009a, 19-20; Prasad, J.D. 2009, 32-4; Rao, P.R. 1994, 37; Sastri 1975, 135).

The Eastern Chalukyas of Vengi (c. AD 624 - 1070) were then to rule the coastal areas of present day Andhra Pradesh and eastern Telangana for over 500 years (Prasad, J.D. 2009, 32; Rao, P.R. 1994, 36-8; Sastri 1975, 135). Both Chalukya lines lived peacefully, with Telangana serving as the frontier zone between the two dynasties. However, the long wars fought with the major southern kingdoms of Pandya and Pallava weakened the Chalukyas of Badami, leading to their downfall towards the middle of the 8th century AD. The emerging power of the Rashtrakutas of Malkhed (c. AD 753 - 973) under prince Dantidurga, a former feudatory of the Chalukyas, gradually undermined them by subduing their outlying provinces and finally by defeating the last ruler Kirtivarman II c. AD 753 (Hampa 2014, 11-2; Murthy, S.S.R. 2009a, 31; Sastri 1975, 141). From there onwards under Dantidurga and his successors Krishna I, Dhruva and Govinda III, the Rashtrakutas increased in strength and expanded their kingdom in all directions, making most of the former Chalukyan empire their own (Hampa 2014, 12-4; Murthy, S.S.R. 2009b, 48-51; Sastri 1075, 142-3).

During this period, Telangana was the frontier between two powerful dynasties and governed by two dominant families; the Chalukyas of Vemulavada and Mudigonda. The Chalukyas of Vemulavada (c. AD 750 – 968) ruled over present day Karimnagar and Nizamabad districts and were the vassals of the Rashtrakutas (Hampa 2014 75-8), while the Chalukyas of Mudigonda (c. AD ? – 1125) ruled over parts of Khammam and Warangal district under the Chalukyas of Vengi (Suryanarayana 2009, 69-80). Their inscriptions and those of their overlords reveal that both families took sides in conflicts and were successful on many campaigns (Suryanarayana 2009). “Their military powers and strategic location helped their overlords to become emperors; and on some occasions, it was particularly their support that decided the fate of either Malkhed or Vengi” (Suryanarayana 2009, 69).

The Chalukya and Rashtrakuta period is considered an epoch of transition, with many new socio-economic developments. Society was by large organised according to the varna system of castes with brahmanas/kshatriya occupying the highest position but there were also cultivators, artisans and mercantile groups (Aruna 2009, 179-92). The period saw unprecedented fragmentation and expansion of the caste system with an astonishing increase in sub-castes, primarily due to the inclusion of many tribal/forest groups in the lower echelons and the increased importance of localism (village identities) in the higher ranks of society (Jha 2004, 196-7). As in the Early Historic period, artisans and merchants were formed into guilds but trade and commerce was in decline during this period and their activities were confined to their respective localities (Aruna 2009, 186, 191). Long distance trade only increased in the 10th century when the Chinese and Arabs began to play a bigger role in Indian revival of trade with the outside world (Jha 2004, 193). The period saw the beginnings of feudal society, where kings had little control over the numerous social, economic and religious concerns of the people but were expected to uphold the social order and protect it from internal and external trouble (Sastri 1975, 147-8). Regions or provinces were administered by princes of the royal family and large tracts of land by loyal kings and chiefs (Sastri 1975, 150-1). This land was further divided and its administration often shared amongst autonomous groups and associations. The primary cell of land organisation was the autonomous village, governed by a village official.

The main source of wealth in this period was agrarian, which was cemented by the widespread donation of land grants as evidenced by many donator inscriptions. Donating land not only increased the area of land under cultivation but also enabled invading powers, such as the Chalukyas and Rashtrakutas, to exert control over rural areas by giving land to local chiefs, temples and brahmins. Sometimes this land was given tax exemption but the majority of the state revenue came from the taxes paid by these new landowners (Aruna 2009, 193-9). To accommodate agricultural expansion, irrigation became important and in the semi-arid conditions of Telangana the building of tanks (reservoirs) was the most common way of achieving this. Building and maintaining of irrigation tanks was undertaken by kings and vassals as well as the prosperous peasantry (Aruna 2009, 198-9).

Buddhism saw a decline in this period, as witnessed by Chinese pilgrim Hieun Tsang who visited Andhradesa around AD 641 (Rao, P.R. 1994. 55-6; Ratnam 2009, 227-33). In its place brahmanism revived and Saivism gained popularity, patronised by the later Chalukyas of Vengi (Rao, P.R. 1994, 55). Jainism, although having only a few pockets of influence amongst the wealthy in the Chalukya periods (Rao, P.R. 1994, 56), was patronised under the Rashtrakutas and their vassals, the Chalukyas of Vemulavada (Jawaharlal 2009, 245-7). Several Jain temples were built during this period by the Vemulavada Chalukyas on their territory, like the temples of Deval Masjid (Bodhan), Tribhuvanatilaka (Kurkyala) and Subhadhama Jinalaya (Vemulavada) (Jawaharlal 2009, 246).

The Rashtrakutas' decline started in the middle of the 10th century which saw the emergence of their successors, the Chalukyas of Kalyani (Hampa 2014, 60-1; Murthy, S.S.R. 2009b, 56-7; Rao, K.S.K. 2011; Sastri 1975, 162-3). Around the same time the Chola Empire, further to the south, rose under Rajaraja who ascended the throne c. AD 985. Rajaraja extended his empire to encompass most of present day Tamil Nadu, Kerala and southern Karnataka (Sastri 1975, 163-5).

3.3.4 Medieval (c. AD 1000 – 1324)

Telangana once more formed the boundary between two colossal powers, the Chalukyas of Kalyani and the Chalukyas of Vengi (later the Chalukya-Cholas) but from there arose a powerful family which was to unite the eastern Deccan and herald a new golden age for Telangana. It is with the rise of the Kakatiyas of Warangal (c. AD 1000 - 1323) that the medieval period starts in the region. Very little is known of the early Kakatiya rulers and their origin is still a matter of contention but recent inscription finds (like the Bayyaram epigraph and Mangallu grant) shed some light. The Kakatiyas probably came to Telangana as commanders of the Rashtrakuta in the late 9th and early 10th centuries AD (Rao, P.R. 1994, 59; Sastry, P.V.P. 2011, 135-6). The earliest reference to a Kakatiya in Telangana was Gunda III who was a general who fought against the Chalukyas of Vengi. His son Erra was granted governorship of Kuvari, a part of present day Warangal district. This established the start of Kakatiya influence in the region from their base in Hanumakonda (and later Warangal) under the subordination of the Chalukyas of Kalyani.

Under a succession of rulers from, AD 1000 – 1158, Kakatiya rule in Telangana was consolidated, and by the reign of Rudradeva (c. AD 1158-1195) most of Telangana appears to have been in the control of the Kakatiyas (Rao, P.R. 1994, 63-5; Sastry, P.V.P. 2011, 145-7).

The decline of the Chalukyas of Kalyani and Chalukya-Cholas in this period saw the rise of many smaller kingdoms, each engaged in constant fight for supremacy. Rudradeva took advantage of this and extended the Kakatiya kingdom to parts of coastal Andhra Pradesh (Rao, P.R. 1994, 66; Sastry, P.V.P. 2011, 148-9). It was further expanded east and south by his nephew Ganapatideva (c. AD 1199 – 1262) who is often regarded as the greatest Kakatiyan ruler. During the last years of Ganapatideva's reign, the southern kingdoms of Kanchi and Nellore fell into the hands of the Pandyas and unrest amongst some of his feudatories threatened Kakatiyan rule (Rao, P.R. 1994, 69; Sastry, P.V.P. 2011, 155-8). With no sons, he left the throne to his eldest daughter Rudramadevi (c. AD 1262 – 1290). Rudramadevi consolidated her position by repelling invasions from the south, however, in doing so lost her life in battle c. AD 1290. (Rao, P.R. 1994, 71-3; Sastry, P.V.P. 2011, 158-61; Sastri 1975, 200-1). The throne fell to her grandson, Prataparudra (c. AD 1290 – 1323) who was to be the last Kakatiyan ruler.

The Kakatiyas ruled in a feudal period and power lay with their authority over loyal chiefs and vassals who paid taxes (tribute) to the state and provided military services for the realm's protection and expansion. The Kakatiyas, especially in their earliest days, were skilled in asserting control over neighbouring chiefs. They would do this by strengthening ties through marital alliances and recompensing loyal service through the donation of land and titles, allowing petty chiefs and generals to become full-fledged feudatories. Those who caused too much trouble were removed and their lands annexed or given to more loyal subjects (Lakshmi, J. 2011, 179-83). All feudatories had their own military and administrative organisations. In addition to these feudatory ties, the nayamkara system was developed during Ganapatideva's reign. With the increasing danger of external forces and internal revolts threatening the empire, a more reliable and permanent military system had to be introduced. Seventy-seven nayakas (generals) were chosen from the most loyal and reliable persons in the military. Up to one-fourth of the kingdom is believed to have been allotted to the nayakas, each in charge of a fort and a military force, and directly under state control, reducing dependence on feudal forces. This was the first system of its kind in medieval India and was later adopted by the renowned Vijayanagara Empire (Lakshmi, J. 2011, 183-84).

Social organisation saw continuity in this period, with greater numbers of people brought into the varna caste system. Due to increased military demand, many tribal communities were incorporated and there was a rise of peasant-warrior groups. The caste system became far more complex with new divisions based on profession, religion movements/beliefs and political affiliations (Pramila 2011, 200-4). Telangana was, for a long time on the peripheries of larger dynasties, relatively free of political disturbances and foreign invasion. The Kakatiyas changed the dynamics by making Telangana the economic and political centre of their empire. Their policies, combined with the decline of neighbouring powers (such as Vengi and Kalyani), created greater social mobility in the region, enabling people to move up and down the social order. This could happen horizontally through the movement of people into new areas or vertically based on economic and political factors (Pramila 2011, 212-5). With the nayamkara system and increased military demands, people of lower social status could rise to hold important governmental and military positions. Peasants-warrior communities like Velamas, Reddis and Kammas were elevated and held greater power in the medieval period, to the extent where many feudatory families ruling over Telangana (under the Kakatiyas) belonged to the fourth (lowest) caste (Pramila 2011, 215-16).

The economy of the period was again primarily agrarian and saw unprecedented agricultural growth in Telangana. The Kakatiyas, like their predecessors built many tanks in the region, making the empire self-sufficient in food-grains. Most villages appear to have been provided by at least one tank of which many can still be seen today (Rao, P.R. 1994, 78). Trade saw a revival under the Kakatiyas, with Telangana at its centre. There was a growth in local (nakaram) and itinerant (samaya) merchant guilds who controlled internal and external trade. One of the largest itinerant guilds was Ayyavali-500 who operated all over South India. “The Telangana region was noted for its iron and steel products, textiles and diamonds” (Pramila 2011, 222). The main trade centres in Telangana were Warangal, Anumakonda and Mattevada but it was also conducted in other important administrative and temple towns like Sirikonda, Gangapuram, Penugallu, Alampur, Govindapuram. The main arteries were the Godavari and Krishna, and river ports such as Vadapalli and Yeleswaram, as well as other towns near crossing points, became important (Pramila 2011, 226-7). External trade with places like China, Indonesia and Italy was also booming, giving importance to the main Kakatiyan ports of Motupalli, Machilipatnam and Krishnapatnam (Parini 2011, 282; Rao, P.R. 1994, 79). Although trade was conducted by guilds, the state encouraged it and retained some control. Officers were stationed at trade centres, sometimes with troops and tax officials collected trade duties. Taxes were an important source of state income and were implemented not only on the products but also on markets and shops (Pramila 2011, 228-30).

The period also saw unprecedented urbanisation which can be attributed to several factors. The rise of many powerful chiefs and families created a need for the development of many administrative capitals. The increase of trade and commerce also helped in creating large urban centres by attracting people and increasing prosperity. Another major factor was the growing importance of the temple, both economically and spiritually. The temple supported a large number of professional communities and servants as well as attracted pilgrims (Pariti 2011, 280-85). The main centres in Telangana were Anumakonda and Warangal. Anumakonda was chosen as the capital by Prola II becoming an important fort city covering c. 5 square miles. It was irrigated by two large tanks and became a centre for trade and commerce. It also holds the famous thousand-pillared temple, built c. AD 1163 by Rudradeva (Pariti 2011, 287-8). The capital was moved to Warangal by Rudradeva where a large fort was built during the reign of Ganapatideva. The fort consisted of three rampart walls with 45 bastions surrounded by two deep water-filled moats. An outer mud fort (Bhumikota) and an inner stone fort (Kalukota) were added by Rudramadevi and can still be seen today. It is believed to have had a large population and became the biggest trade centre in the Kakatiyan period, specialising in textiles, woollen and metal industries.

Repeated Muslim attacks and invasions at the beginning of the 14th century AD set the Kakatiyan Empire into decline. The first invasion by the Sultan of Delhi, Ala-ud-Din Khalji in AD 1303 was successfully repelled but the second in AD 1309 resulted in Prataparudra to sue for peace, at huge cost, after a siege of Warangal (Rao, P.R. 1994, 75; Sastri 1975, 207-8; Sastry, P.V.P. 2011, 164). But threats from the north continued to weaken Kakatiyan rule and a succession of invasions from Delhi led finally to Ulugh Khan, in a fifth invasion, forcing the surrender of Warangal and the capture of their king Prataparudra. This ended Kakatiyan rule and saw the start of Muslim dominance in Telangana (Rao, P.R. 1994, 76-7; Sastri 1975, 211-2; Sastry, P.V.P. 2011, 167-9).

3.3.5 Late Medieval (c. AD 1324 – 1724)

After having consolidated his position in the South by conquering most of the Kakatiyan subordinates, Ulugh Khan returned to Delhi where he was crowned Sultan Muhammad Shah (Muhammad bin Tughlaq) after his father's sudden death in AD 1325 (Prasad, J.D. 2014a, 9-10). He left the area constituting the former Kakatiyan Empire under Malik Burhanuddin, Premier of Devagiri, and Malik Maqbul as governor of Warangal. Muslim rule is said to have been oppressive, whereby the predominant Hindu populations suffered hardship and intolerance with the destruction of temples and heavy taxation causing even the wealthy to revolt (Prasad, J.D. 2014a, 9-11).

This first wave of Muslim rule did not last long. The following century saw the rise of several small kingdoms that pushed the Muslim invaders back. The majority of these rulers were Kakatiyan generals (nayakas and other nobles) which had once administered parts of the empire (Prasad, J.D. 2014a, 11-2; Rao, P.R. 1994, 82; Sastri 1975, 214). Plagued with these revolts, the Delhi Sultan, Muhammad bin Tughlaq, brought an army in the mid AD 1330's to Telangana but an epidemic forced him to retreat to Devagiri (Sastri 1975, 215-6). Before returning to Delhi he recognised the futile effort of controlling the Telangana region from Devagiri (situated in central Maharashtra) so divided it into two administrative parts. The eastern region was placed under Malik Maqbul, with headquarters at Warangal while the western parts was controlled by Shihabi Sultani, with Bedar as his headquarters, both under the new Premier of Devagiri, Qutlugh Khan (Prasad, J.D. 2014a, 16). After the Sultan's departure, Musuniri Kapaya Nayaka sprang into action and with the support of local chiefs and kings managed to regain control of Warangal in AD 1336 (Rao, P.R. 1994, 90; Sastri 1975, 216). The southern rebellions could not be put down by the Sultan who was preoccupied with widespread revolts closer to home, leading to the loss of the majority of the peninsular, only retaining parts of Maharashtra and Gujarat (Prasad, J.D. 2014a, 16-7).

Other kingdoms that rose from the disintegration of the Kakatiyan Empire and brief Muslim rule were the Reddi Kingdoms of Kondavidu (c. AD 1325-1424) and Rajamahendravaram (c. AD 1391-1448) as well as the Vijayanagara Empire (c. AD 1336-1660). The Reddis' first ruler was Prolaya Vema Reddi and at their zenith they ruled over the whole coastal track of present day Andhra Pradesh. The Vijayanagara Empire was founded by Harihara I in AD 1336 and dominated the southernmost part of India for over three centuries. Their influence was mostly confined to the areas south of the river Krishna, at their zenith including the entirety of present day Karnataka, Kerala, Tamil Nadu and parts of Andhra Pradesh (Prasad, J.D. 2014b; Rao, P.R. 1994, 92-129). Although both dynasties played a role in the shaping of the Telangana region through contact and conflict with their rulers, neither had direct control of the area, therefore they will not be discussed further here.

Around the same time, developments were occurring in the west with the emergence of the Bahmani Kingdom of Gulbarga and Bidar (c. AD 1347 – 1538) (Farooqui 2014a, 87-8; Prasad, J.D. 2014a, 17-8; Sastri 1975, 219). The Bahmanis attacked Telangana in AD 1350, taking the fortress of Kaulas, and again in AD 1356, resulting in Bhongir (Nalgonda district) being ceded. These attacks weakened the local feudatories putting parts of western Telangana under Bahmanis control (Farooqui 2014a, 89; Prasad, J.D. 2014a, 18-9; Rao, P.R. 1994, 90; Sastri 1975, 221).

Trouble also reigned closer to home, where the Recherla Padmanayaks began asserting their position in Telangana. This saw the ascendency of the Recherla chiefs, ruling from their joint capitals Rachakonda and Devarakonda (Prasad, J.D. 2014a, 20; Rao, T.D. 2014, 35-7; Rao, P.R. 1994, 90). At their fullest extent, the Recherla chiefs controlled most of Telangana (except the westernmost part) and parts of Andhra Pradesh (Kurnool and Guntur districts). The Recherlas succeeded in keeping control of this area, surviving many wars against their Hindu neighbours, the Reddis and Vijayanagar, until the kingdom was gradually annexed by the Bahmanis between AD 1433 - 1470 (Rao, T.D. 2014, 37-9). The Bahmanis after long and ferocious wars fought with the Vijayanagar Empire, Malwa and Gujarat (Farooqui 2014a, 90-4) as well as detrimental (political) internal strife, disintegrated towards the end of the 15th and early 16th century AD to form five independent Deccan sultanates – Bijapur, Ahmednagar, Golconda, Bidar and Berar (Chandra 2007, 148; Farooqui 2014a, 95; Rao, P.R. 1994, 139; Sastri 1975, 235).

One of these new Sultanates, the Qutb Shahis of Golconda (c. AD 1518 – 1687) ruled for almost two centuries over a geographical region similar to that held by the Kakatiyas of Warangal in the medieval period, including the majority of Telangana (Ali 2014, 98). Sultan Quli Qutb-il-Mulk founded the dynasty. He originated from Central Asia and came to serve under the Bahmanis. In AD 1496 his loyal service was rewarded with the fief of Golconda making him governor of Telangana (Rao, P.R. 1994, 139). His kingdom was limited to the land between the Godavari and Krishna Rivers but after claiming independence in AD 1518 he conquered the remaining Gajapatis and Reddi chiefs in the East extending his kingdom to the river deltas (Ali 2014, 99-100).

The reign of Ibrahim Qutb Shah, who gained the throne of Golconda in AD 1550, marked the assimilation of the nayakas, who controlled many Telangana fortresses and had refused to give loyalty to the early rulers of Golconda. It was also during his reign that the Sultanates formed a confederacy against the Vijayanagara Empire winning at the famous battle of Bannihatti (Talikota). During Ibrahim's rule, peace, tranquillity and economic prosperity are said to have prevailed but this did not stop him from annexing modern day Krishna district, extending his sway over the eastern coast (Ali 2014, 102-4). Under Mohammed Quli Qutb Shah, who ascended the throne in AD 1580, the new capital Hyderabad (Bhagyanagar) was founded and the famous monumental structure of Charminar was built (Ali 2014, 104-5). Abul Hasan Tanashah gained the throne in AD 1672 and was the last of the Qutb Shahi rulers. In AD 1685 the now Mughal Sultan Aurangzeb ordered the invasion of Qutb Shahi territories and after two years of warfare and a long siege at Golconda, Abul Hasan (betrayed by one of his commanders) was captured in AD 1687, putting an end to the dynasty and the start of Mughal rule (Ali 2014, 108-9; Rao, P.R. 1994, 148).

The late medieval period in Telangana was marked by two main phases, the disintegration of the Kakatiyan Empire leading to the rise of small Hindu kingdoms, and the invasion of Muslim rulers. The way of life during the first phase changed very little from the preceding period, as many Kakatiyan principles in matters of polity and administration persisted (Sastry, C.A.P. 2014, 138). Significant changes came during Bahmani rule, which adopted a system similar to that of the Delhi Sultanate. The king embodied the supreme power in the state, with vested powers of ruler, judge, administrator, military leader and sometime even leader of public worship (Farooqui 2014c, 158-9). Administration was overseen by ministers who were in charge of external affairs, finances and judicial matters as well subordinate ministers in charge of civil and military matters (Farooqui 2014c, 159). The kingdom was divided into four provinces (tarafs) and Bahmani Telangana was one of these. The governors (tarafdars) had control over most civil and military administration in their territory and as the kingdom grew, their powers also increased. This became a concern in the 1470's and considerable efforts were taken to re-centralise power. Unfortunately these efforts were not enough to stop the Bahmani state from disintegrating later in the same century.

Attempts to centralise administration were also taken by the Qutb Shahis of Golconda. In their early years of rule, the kingdom was not divided into provinces and the sultan's power and authority was supreme. However, from AD 1565, with the increased acquisition of territory, a provincial system had to be developed and the kingdom was divided into six provinces, each under a governor. Although the central administration was tightly controlled by the sultan, the provinces, especially ones on the periphery of the kingdom often acted as they pleased (Farooqui 2014c, 164). The Qutb Shahis developed efficient judiciary, police, army and intelligence administration. This administration was run by a number of officers, the most important of which was the peshwa who governed the state in the name of the sultan with the help of twelve ministers. An efficient postal system was also developed. These worked on a runner system whereby huts were constructed every five miles on highways from which runners would carry the letters to the next hut until the delivery was completed (Farooqui 2014c, 165-6). Land was divided into mouzas (village) which many combined made up a taraf which in turn made up a pargana. With the increasing difficulties of centrally controlling a growing kingdom, some fiscal rights were given to the aristocracy. Revenue farmers (sarsamatus) and ministers who possessed (or rented) tracts of land became the aristocracy, increasing their administrative power. Although this system was successful in expanding agricultural production and trade, some problems arose as many nobles developed local roots and started acting as feudal lords (Farooqui 2014c, 166-7).

The late medieval period saw the most change in the social fabric of the region. The primarily Hindu population followed the varna system, which grouped people into caste-divisions which by now were mostly determined by occupation and regional identities. The arrival of migrant populations, foreign settlers and rulers, brought new cultural values and ethics which disturbed this social order. Muslims from Central Asia made up the most numerous foreign component but there were also Christian westerners (notably English, French, Dutch and Portuguese) who came as traders and formed elements of the artillery regiments in the military. The rising economic prosperity in this period saw these differing social groups compete for social honours (Rao, K.S.K. 2014, 315-6). The 'alien' Muslim rulers adapted to this growing social diversity by incorporating local customs and allowing Hindus to occupy high administrative positions. This cultural synthesis was further expanded with the interaction of liberal sects which gave rise to the blending of Islamic and Hindu traditions. Hence society in this period became "less rigid and more open by allowing internal and external liberal winds to influence the behavioural patterns of social groups" (Rao, K.S.K. 2014, 315). Late medieval Telangana was very much in a transitional phase, with a shift from rural to urban activities and a shift from an agrarian to mercantile economy. The settling of foreigners made society increasingly multi-lingual, multi-religious and multi-cultural (Rao, K.S.K. 2014, 315-6). It was in this period that European and Persian travellers such as Marco Polo, Tavernier, Thevenot and Bernier visited India, leaving rich accounts of their journeys (Anjaiah 2014, 217).

The late medieval period was prosperous with an increase in food production and both internal and external trade. In fact, the kingdom of Golconda under the Qutb Shahis was only second to the Mughal Empire in terms of wealth (Farooqui 2014d, 195). It saw the introduction of large scale irrigation for revenue farming. Land was leased out from which the state took one-half of the produce of each harvest as land tax. This tax was collected by officials but the district governors could raise taxes as they wished to fill their pockets, sometimes at the expense of the peasantry. The main agricultural products were tobacco, rice, wheat, corn, sugarcane, chillies and onion (Farooqui 2014d, 196-8).

The region also had flourishing rural industry which contributed significantly to its prosperity. The textile industry (cotton and silk) was well established since medieval times and the Qutb Shahis established state owned factories. Carpet weaving was reputed in Warangal, Eluru, Kazipet, Hanumakonda, Parkal and Hasanparthi (Anjaiah 2014, 218-21; Lakshmi, R.V. 2014, 311). Metalwork also reached a new height with goldsmiths and silversmiths established in most urban centres. Of more importance to this study is the widespread manufacture of iron and steel needed to equip the armies and provide for the domestic needs of the population. The Qutb Shahi rulers gave priority to artillery, with the manufacture of cannons and ammunition as well as military equipment. Centres of production included Nirmal and Indur in Nizamabad district. It is also to this period that crucible steel manufacture is reported by foreign travellers (Anjaiah 2014, 226-9). In addition to metals, a large part of the region's wealth was in its diamond mines found in

Anantapur, Kurnool, Kadapah and Guntur districts of Andhra Pradesh. The kingdom of Golconda was famous for its production of diamonds which were exported widely (Anjaiah 2014, 221-6; Rao, P.R. 1994, 152-3).

With surplus agrarian and industrial goods, trade saw an unprecedented growth in the late medieval period. Internal trade was undertaken via the many roads which connected larger urban centres, and merchants started to move around in large caravans for added security against robbers (Reddy, N.K. 2014, 234-5). Most towns appear to have had market or fair days, which not only allowed villagers to sell surplus goods but also acted as a vehicle between town and village for exchange of commodities. The rise of trading and growing demand for saleable goods must have affected the self-sufficient economy of the villages which probably began to rely more and more on a market economy (Reddy, N.K. 2014, 235-6). Foreign trade also flourished in this period and Coromandel ports such as Visakhapatnam and Motupalli became important in the early days (Reddy, N.K. 2014, 236) but were overtaken by Masulipatnam and Nizamapatnam which became the main ports of Golconda (Reddy, C.S. 2014, 246-7, 252). Trading occurred mainly with Europe, China, Sri Lanka, South East Asia, Arabia and Persia, who not only bought Indian goods but also sold their own. Horses, elephants, silk, camphor trees, civet, aloe wood, sandal wood, rose water, musk and perfume are just some of the imports prized (Lakshmi, R.V. 2014, 308; Reddy, N.K. 2014, 236). Due to its large size and strategic location, Hyderabad consumed a major portion of imports from the northern Coromandel ports and the entire road from Hyderabad to Masulipatnam was dotted with production and marketing towns (Reddy, C.S. 2014, 250; Rao, P.R. 1994, 153). The Qutb Shahis encouraged trade by granting land (farmans) and exemptions to foreign traders (Lakshmi, R.V. 2014, 308). By the middle of the 17th century AD several European Companies had founded towns and built factories on the eastern coast (Reddy, C.S. 2014, 247).

The settling of numerous foreign immigrants increased economic prosperity, trade and commerce, and improved means of transport and communication in the late medieval period accelerated urbanisation (Lakshmi, R.V. 2014). Golconda, which had been a minor Hindu fort in the medieval period was adopted as the capital of the Qutb Shahis and became the biggest centre of trade and administration for a large part of the Deccan, overtaking Warangal from the previous period (Lakshmi, R.V. 2014, 306). This centre shifted to

Hyderabad when it was founded in AD 1591, replacing Golconda as capital. The cities of Hayatabad and Ibrahimpatnam were also founded sometime shortly after Hyderabad (Lakshmi, R.V. 2014, 306-7). In addition to cities, forts served as administrative headquarters for districts and provinces and by the time of the Qubt Shahis, they also became important trade and cultural centres. Due to the introduction of gunpowder artillery, most mud-fort defensives were upgraded or replaced with stronger, stone constructions (Lakshmi, R.V. 2014, 306). The most important fort in Telangana was Golconda which rose in importance first under the Bahmanis and then the Qubt Shahis. Other important forts were Kondavidu (Guntur district), Kondapalli, Bhongir (Nalgonda district), Kaulas (Nizamabad district), Medak, Warangal and Kovilkonda (Mahaboobnagar district) (Murthy, N.S.R. 2014, 479-84).

Although Hinduism in the form of Saivism and Vaishnavism dominated in the late medieval period, Islam was introduced and patronised by the Muslim Tughlaq, Bahmani and Qubt Shahi rulers. Islam came to the Deccan first with the growing influence and settling of Arab, Persian and Central Asian merchants. The faith was then fully established when the Muslim rulers of the north (Delhi Sultanate) extended their kingdom into the Deccan (Farooqui 2014e, 412-14). Different Islamic faiths were patronised throughout this period. Sunnism and Shiaism were the most common but Sufism also spread. Sunnism was followed by the Tughlaqs and Bahmanis but the Shia faith was patronised under the Qutb Shahis. The Islamic faith seems to have been well integrated in society with both Hinduism and Islam co-existing peacefully (Farooqui 2014e, 415). The Qutb Shahis aided many religious institutions of both Hindu and Islamic faiths which helped maintain harmony in society.

The Mughals only ruled in the Deccan for a brief period, partially due to the political disarray and unrest caused by Sultan Aurangzeb’s death in AD 1707. After his death, wars of succession were fought between his sons. The rulers who gained the throne after Aurangzeb were unable to effectively re-establish control over the growing power and unrest of the nobility (Farooqui 2014b, 115-6). One such noble was Chin Qilich Khan, who was appointed as governor of the six subas of the Deccan in AD 1713 and given the title of Nizam-ul-Mulk. The Nizam was ambitious and wanted to rule the Deccan independently. He took advantage of the fragile political unity of the Mughal Empire to carve himself a kingdom and after several wars fought against opposing nobles, managed to secure his hold of the Deccan by AD 1720. In AD 1725 the Mughal Emperor awarded him the title of Asaf

Jah after he had gained control of Hyderabad. This was the start of his autonomous rule and laid the foundations of the state of Hyderabad under the Nizams of the Asaf Jah dynasty (Farooqui 2014b, 116-8).

4 Methodology

4.1 Assessment of the Archaeology Field Data

In order to gain greater understanding of the ancient metallurgical technologies in Northern Telangana, the assessment and characterisation of the archaeometallurgical sites recorded during the Pioneering Metallurgy Project is crucial. It is important to mention here that all data used in this study, including site descriptions, photographs and GPS coordinates, were collected during the Pioneering Metallurgy Project (2010-2011) and adapted by the author to formulate site types and assess trends. Information on the aims, objectives, methods and tentative results of the Pioneering Metallurgy Project can be found in the project interim report (Juleff *et al* 2011). The main data collection and storage methods will be summarised below, followed by the processes by which it was adapted and used in this study.

4.1.1 Pioneering Metallurgy Fieldwork

The Pioneering Metallurgy Project was instigated in 2010 and completed in 2011 as a joint research enterprise between the University of Exeter and the National Institute of Advanced Studies (NIAS), Bangalore. The lead investigators were Dr G. Juleff, Prof. S. Srinivasan and Prof. S. Ranganathan supported by Dr B. Gilmour and Dr S. Jaikishan. Students from the University of Exeter and the Dharmapuri Graduate College (Telangana) participated, including the author. The fieldwork took place over a period of six weeks from January-March 2010 in the four northern districts of Telangana state, Adilabad, Nizamabad, Karimnagar and Warangal. The fieldwork was primarily focused within Karimnagar district, centred in an area c.50km diameter around the town of Dharmapuri, with some probing into neighbouring districts up to 100km from the centre to incorporate specific known locations (Juleff and Gilmour 2011, 8). Without permission to excavate, the aim of the fieldwork was to survey as many locations as possible relating to iron and steel manufacture. Although the purpose was to explore known sites to carry out recording and sampling, new sites were occasionally identified throughout the course of the fieldwork (Juleff and Gilmour 2011, 8). The fieldwork encompassed several aspects of recording, including detailed location/site surveys, sample collection and interviews of local inhabitants who may have had knowledge of the archaeological remains. This section will not deal with material sampling or interviews but will focus on the methods of recording locations of interest during the survey. The most important locational data is provided in appendix A.

4.1.1.1 Site Survey and Data Collection

The field survey comprised a 12 person team led by Dr Gilmour and Dr Jaikishan. The methodology and recording was based on similar research led by Dr Juleff in Sri Lanka (Juleff 1998), and can be broadly described as reconnaissance survey. Juleff's research focused on the recording of archaemetallurgical features in the Samanalawewa region of Sri Lanka. The methodology employed in that context proved very effective in collecting detailed data quickly from a large geographical area. It also proved effective in the identification of past metallurgical smelting and crucible steel activities. The similarity in work and environment of the Pioneering Metallurgy Project was ideal for a similar survey-style approach.

The survey consisted of daily excursions by vehicle and on foot to known sites which were then recorded using GPS, photographs and descriptive data taken by all survey team members using field notebooks. GPS tracking (with a Garmin etrex) was used to record and map the routes taken during the day. The majority of the information however, was recorded in the individual field notebooks kept by each member of the team. Notes were taken as continuous expansive narratives starting each morning at base camp, recording routes travelled, significant landmarks and landscape features, changes in land use, agriculture, village settlements and individuals encountered in the course of the day (Juleff and Gilmour 2011, 8).

Important features were recorded as distinct 'locations', encompassing various forms of evidence such as metal-working activity, geological features, buildings or structures, find-spots or persons interviewed (Juleff and Gilmour 2011, 9). Each location was ascribed a 'date/location' number comprising the date followed by a sequential number specific to that date, e.g. 12/02/10 (1). This avoided assigning 'site' status at the outset, allowing multiple loci within a particular settlement or larger metallurgical complex to be recorded separately, avoiding potential important information being lost within more generic accounts of the whole. It also allowed for the fine resolution of data compilation in the later analysis stage (Juleff and Gilmour 2011, 8). These location settings were eventually reviewed by the author and some grouped to form ‘sites’ proper. The methodology employed to do that will be discussed in the following section 4.1.3.

In total, 224 locations of interest were recorded. Due to the large extent of the area surveyed, relatively little time could be spent at individual locations. The time spent at each location varied from a few minutes to a few hours, depending on the size of the feature as well as its potential importance to the project as a whole, primarily focusing on the direct evidence of ancient iron and steel production, i.e. smelting and crucible waste deposits (Juleff and Gilmour 2011, 9). On average, more than seven locations per day were recorded with some important areas being re-visited. This enabled large tracts of the region to be covered but provided more of a reconnaissance survey rather than an in-depth analysis of each feature (Juleff and Gilmour 2011, 9). This was mitigated in part by the large team which permitted work to be divided amongst smaller groups, each focusing on different recording tasks at each location, allowing for greater efficiency and speed. Along with taking GPS coordinates and photographs, these tasks included more in-depth note taking and material sampling. Samples were taken from every metallurgical location as well as many of the geological locations which had evidence of iron ore. The process in which the samples were chosen and later processed will be discussed in chapter 4.2.

GPS coordinates were taken (using a Garmin etrex) for each location usually in the centre of the feature but additional points were taken for larger features at the edges to record their extent. The coordinates were both stored electronically (with a daily tracker) and on a written GPS log. Official photographs were taken by a selected member of the team and the photo numbers also recorded in a log. In addition, all individuals with a camera took photographs throughout the day to record features, landscape settings and team members at work. Note taking focused on recording the landscape setting, the features present, the technological material present as well as approximate size of features and their state of preservation. This was especially relevant to the iron smelting and crucible steel waste heaps where it was important to record whether or not the residue was *in situ* and to what extent had it been disturbed by human activities. Wherever was deemed necessary, location sketches and plans were also drawn to help support field notes. Features were roughly measured through pace counting and their height approximated with a 1m scale.

4.1.2 Data Storage and Digital Database

The huge amount of data collected during the fieldwork had to be organised systematically to offer a clearer picture of the metallurgical setting within the landscape of the region. This data included the GPS coordinates, photographs, written description notes and material samples. An attempt has already been made to make sense of this large amount of data and the tentative results were published in the project interim report (Juleff and Gilmour 2011; Cox and Haricharan 2011; Neogi and Jaikishan 2011; Oltean *et al* 2011). However, only preliminary results and interpretations were provided based on the analysis of small parts of the full dataset. For this reason, this section will not focus on these preliminary results but on how the data was managed and organised post-survey. A more detailed methodology for the post-survey treatment of location data can be found in Juleff *et al* (2011, 24-6).

As previously mentioned, both GPS coordinates and photographs were noted in a field log while the majority of the location descriptions were written in individual field notebooks kept by everyone on the team. In the field, after each work day, the notes and interviews taken by all individuals were gathered, transcribed and/or synthesised into one central project daily diary, while the photographs were uploaded and stored in folders organised by date. Another field log was also created to help keep track of all individual locations by including a brief description, the physical location, GPS coordinates and sampling references. The samples collected from metallurgical locations were also washed, sorted, weighed and bagged every evening. Clear sample numbers were ascribed to every bag of material allowing clearer reference to their associated locations. A separate log was created for charcoal, soil, pottery, iron and metallurgical waste samples. This will be discussed in more detail in the following section 4.2.

All field written notes and logs were transposed into a digital database post-survey. This involved creating a pro-forma location record form, whereby all data pertaining to individual locations could be brought together (Juleff *et al* 2011, 25). The chosen platform was Microsoft Access and an example of the form is shown in figure 4.1. The lengthy and complex process of collating and compiling the survey data into a single database was in progress at the outset of the current project and completing the task using the procedures established became an early objective of this study. Approximately half of the data entry was completed by the author. Part of this process included making sure all information fields were coherent and standardised across its entirety. Its creation provided a single source of access for the huge quantity of data points generated during the survey. The entirety of the information it contains cannot be provided in this study but a table was created with the most relevant data for each location in appendix A.1.

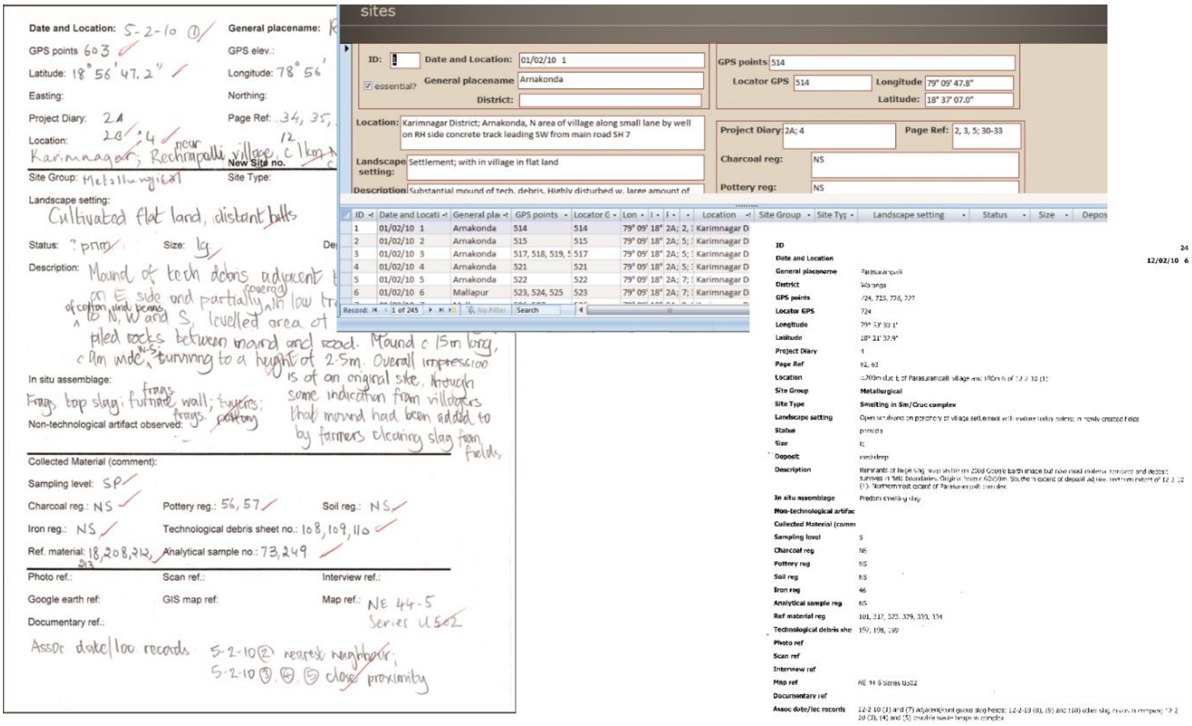


Figure 4.1 – Example of date/location records using pro-forma sheets to transpose data from field notes into Microsoft Access database entry (adapted from Juleff et al 2011, 25).

The data was divided into four main categories; locational and administrative, location description, sampling, and cross references to other relevant sources (Juleff *et al* 2011, 25). The locational and administrative data included GPS coordinates, district and local place-names, location description and archival cross-references to project diary pages. The location description comprised landscape setting, site group and type, size and condition of the location or deposit and general description of the features and visible assemblages. The sampling section consists of noting the material sampled and giving cross-references to sample register numbers. The cross references to other relevant sources encompasses photographs, maps, documentary sources and interview records (Juleff *et al* 2011, 25). In addition, a section was included for noting possible associated locations. These were identified either due to their physical proximity, shared features and/or similarity of the technological assemblages, and gave a first opportunity to start grouping locations together which might be later considered as 'sites' or site types (Juleff *et al* 2011, 25).

The following sections will highlight the kinds of data categories created to characterise locations and assess trends. Three elements were deemed crucial in the assessment of the data. Location groups and types which was based primarily on the physical evidence present, location status which concentrated on the size, depth and preservation status of features, and location setting focusing on the geographical and landscape setting.

4.1.2.1 Location Groups and Types

Of special relevance to the characterisation of the sites in this study, was the categorisation of the locations into groups and types. All recorded locations were divided into four main groups, historic, geological, ethnographic and metallurgical, with each encompassing several location types. The location groups and types are summarised in table 4.1 below. The historic group included a range of types such as temples, forts, settlements and structures of interest. The geological group incorporated quarries, potential ore sources and mining pits while the ethnographic locations were either blacksmith workshops or interviewed persons. The metallurgical locations were the primary focus of the project and included iron smelting and crucible steel waste remains. However, it became clear at an early stage that many metallurgical locations had evidence for both iron smelting and crucible steel production, more often than not with a dominant technology type. To account for these, two more categories were formulated, crucible/smelting and smelting/crucible locations, the first category depending on the dominant technological waste material observed at these locations. Although some may have had evidence for other technologies (such as smithing), they were all characterised within these two main technologies, smelting or crucible.

Table 4.1 – Location group and type categories based on physical remains and technological residues present.

Loc. Group	Loc. Type	Description
Historic	settlement	Location is an old settlement (usually uninhabited)
	temple	Location is a temple
	structure	Location is an individual building structure (not a temple)
	pottery scatter	Location is a surface scatter of pottery
	megalithic	Location with megalith burials
Geological	ore deposit	Location is a potential source of iron ore as ores are found here
	mining pits	Location is a potential source of iron ore with evidence of extraction
	quarry	Location is a source of other minerals with evidence of extraction (not iron ore)
Ethnographic	operational smithy	Location is a blacksmith's workshop/area currently still in use
Metallurgical	smelting	Location with evidence for smelting only
	crucible	Location with evidence for crucible steel production only
	smelting/crucible	Location with evidence primarily for smelting but also some crucible steel production
	crucible/smelting	Location with evidence primarily for crucible steel production but also some smelting
Any	findspot	Location of individual or very few finds of potential interest

4.1.2.2 Location Size, Deposit Depth and Preservation Status

To facilitate intra-location comparisons, certain descriptive attributes were simplified. These included the location size, the deposit depth and the preservation status. Each of these were divided into three descriptive categories; small, medium and large for size; shallow, medium and deep for the deposit depth; and primary, disturbed and secondary for the preservation status. The parameters of each category is described in table 4.2 below. This grouping of descriptive traits allows for qualitative assessments to be analysed quantitatively, helping to analyse the data statistically. It allows easier comparisons to be made between locations/sites and identify more general trends. This approach was extended further to encompass other locational descriptive data, primarily location setting, which will be discussed in the following section.

Table 4.2 – Database categories and their abbreviations of location size, deposit and preservation status.

Size	qualitative assessment of relative location size	
	sm.	small - <25m2
	med.	medium - 25-100m2
	lg.	large - >100m2
Deposit	qualitative assessment of deposit depth	
	sh.	shallow - <0.1m
	med.	medium - 0.1-0.5m
	deep	deep - >0.5m
Status	qualitative assessment of deposit quality	
	prim.	Primary, mostly undisturbed deposit
	dis.	Primary, but disturbed deposit
	sec.	Secondary deposit not in original location

4.1.2.3 Location Setting

Another relevant descriptive category is the land use/landscape setting in which the locations were situated. The information transcribed into the digital database was a descriptive narrative of the setting with reference to either natural or man-made features/land use. However, this qualitative data made it difficult to statistically analyse locations, so the author simplified the information into a series of prescribed locational categories. These location type categories and their abbreviations are outlined in table 4.3. Special attention was paid to differentiating between locations within or on the edge of settlements and those found further away from human habitation, in agricultural land, bare scrubland or forests. The categories are self-evident, with locations within settlements noted as ‘S’, those in agricultural land as ‘A’ and so on. It is also important to mention that many locations straddled several categories. In this case, they were given more than one locative abbreviation (e.g. A-BS). The first abbreviation corresponding to where the majority (or main feature) of the location is found, while the second corresponds to the setting in which it encroaches upon. This was particularly relevant to locations on settlement edges. Those immediately touching a settlement were labelled as ‘SE’ but those within 150m from habitation were given a first abbreviation where the location was found followed by ‘SE’; for example, a location within agricultural land surrounding a settlement (<150m) was given ‘A-SE’. Although most of the location settings were recorded during the fieldwork phase and documented in the digital database, all locations were re-checked using Google Maps. The main coordinates of each location were plotted into Google Maps (with topographic, street and satellite filters) and the location settings checked against the recorded descriptions. This helped refine some of the locative information provided in the digital database and confirm, for example, in which part of a village a location was situated or conversely the distance from a settlement.

Table 4.3 – Land use/landscape setting categories in which locations were recorded.

Location Type	land use/landscape in which location is found	
S	Settlement	location within habited settlement
SE	Settlement edge	location on the exact periphery of habited settlement
BS	Bare scrubland	location within a patch of fallow scrub dominated land
A	Agricultural	location within agricultural fields, plantations or groves
F	Forest	location within dense forest
H	Hill	location on or at base of a hillock or hill
A-SE	Agricultural/ settlement edge	location within agricultural fields or groves on edge (<150m) of habited settlement
BS-SE	Bare scrubland/ settlement edge	location within bare scrubland on edge (<150m) of habited settlement
Any-Any		first abbreviation location type is where main bulk of location is found but encroaches upon second abbreviation

4.1.3 Site Characterisation and Typology

The next task of this study was to make a full assessment of all locations, integrating all the data, to assign final 'site' status. This section will outline the methodology employed to create the final sites.

Out of the 224 locations recorded during the Pioneering Metallurgy Project, 139 'sites' were created. Locations were grouped after consideration of several attributes, primarily distance from one another and similarity of waste material present. Locations were only grouped to form sites if they were part of the same location group and type (discussed above). For example, a location in the historic group was not coalesced into a site with a location in the metallurgical group, irrespective of distance between locations. Concurrently and of more relevance to this study, locations of different types were also not grouped into a site. For example, a metallurgical location in the smelting type was not merged with a crucible/smelting or smelting/crucible location and vice versa.

The main attribute considered for site creation was distance between potentially connected locations. To obtain accurate distances, the main GPS coordinates of each location were plotted on Google Maps using a software called GPSVisualizer. Each point was labelled by its location/date number and the distance was measured using the provided measuring tool. It is important to note that measurements were taken from two points in a straight line (as the crow flies) but the topographical/satellite map overlaid by a street map (settlements and roads) allowed better contextualisation of each location position in relation to the landscape, man-made features and other locations of interest. In addition to these measurements, the detailed descriptions/observations recorded in the diaries and final digitised location records were taken into account. As a general rule, any locations less than 150m from one another were considered to be grouped into a site. This distance was chosen after all the locations were finalised into the digital database and mapped on GPSVisualizer, where it was noticed that most location groupings (possibly associated) occurred within a 150m radius (see chapter 5). It is also worth mentioning that many locations were either touching one another, part of the same feature or very close (only a few metres apart). A good example were the forest sites (see chapter 5.1.4). These, comprised multiple small mounds of waste material many of which were given different location numbers. Their proximity to one another (typically less than 20m) suggests that they could have been contemporary or at least associated. The greatest majority of sites, however, had been recorded as single locations.

In the case of the metallurgical sites, the most important factor in assigning 'site' status was the similarity of the waste material present. If locations were close (<150m) and contained very similar material types, then they were grouped to form a site. It is important to note that sites were not created prior to the detailed observation/recording of the huge material assemblage collected (see chapters 4.2 and 6). Having a clear idea of what types of archaeological material occurred at each location, helped form an early understanding of the kinds of technologies present and their distribution, prior to site creation. In the absence of more concrete scientific dating methods to ascertain whether locations were contemporary, distance and similarity in waste material was a good indicator in identifying possible associated locations which could then be grouped to form 'sites'.

Once all locations were reviewed and those similar combined to form sites, a decision had to be made as to which of the GPS coordinates, locational categories, size and preservation status would be used to represent the sites. As a general rule, the location forming the largest and most dominant feature within the site was selected to represent it. Therefore, the GPS coordinates of the most dominant features/locations were used but more consideration and weighting was given to the other descriptive categories to give the best possible representation of the whole. The size of the site was determined by the combined area covered by all locations, the depth of the deposit taken from the deepest while the preservation status was chosen based on the status of the majority of the remains. Lastly, the location setting abbreviations were combined. The setting where the majority of the remains were located formed the first abbreviation while the others followed in order of importance. It is important to mention, that in most cases, there was little difference in the locations grouped to form a site with most having similar preservation statuses and location settings. In the few instances where there was no clear dominant feature/location, the GPS coordinates of the most central location was taken. New site numbers were created, using the prefix 'PM' for Pioneering Metallurgy followed by sequential numbers such as PM1, PM2 and so on. There was no particular pattern for ascribing site numbers but the location data was worked through in order of site/location field visit. Refer to appendix A.1 for information, typologies and descriptive categories of the individual locations recorded during the Pioneering Metallurgy Project and appendix A.2 for the finalised sites.

4.1.4 Data Processing and Analysis

After site finalisation, the data was coalesced into a large table (appendix A.2). This table includes; site numbers, locations forming the sites, the general placename of the nearest settlement, the site group, site type, location type, preservation status, size and deposit depth as well as the main GPS coordinates. The first step was quantifying the main dataset to determine how many sites fell within each site group. All data was transposed into Microsoft Excel enabling easier manipulation and quantification. The sites within each site group were counted and separated so that they could be assessed independently. A pie chart was created to quantify all sites segregated by group type (see Figure 5.1). The same was done at site group level to quantify sites by site type with individual pie charts created quantifying the results by number and percentage of sites (see chapter 5.1). Each site type was discussed separately in text and the general trends of the sites were described. Larger sites or those deemed to be of greater importance to the study are discussed in more detail (chapter 5.1). This included more detailed aspects of location, size, preserved remains or features and potential association to other sites. To support the observed trends and features discussed in text, photographs and maps were included, providing visual representation. All photographs used were taken from the Pioneering Metallurgy Project, while all maps were created with GPSVisualiser.

After site classification and quantification, the properties of the metallurgical sites were analysed. The first step was to quantify the overall number and percentage of metallurgical sites with specific properties. This was illustrated with individual pie charts for each of the four main properties recorded; size, deposit depth, preservation status and setting (see chapter 5.1.4). The second step was to compare these site properties to the three main site types; smelting, smelting/crucible and crucible/smelting, to identify any potential trends. Several graphs and charts were tried to best represent the data trends. Due to the nature of the dataset, comprising two set categories (site types and properties), the data was best represented using Microsoft Excel stacked column charts. Trends were then discussed in text and several interpretations were proposed (chapter 5.2).

4.2 Visual Macro-morphological Assessment of Material

The detailed visual examination of an archaeometallurgical waste assemblage is an instrumental step in identifying the metallurgical technologies that made and formed the remains (Bayley *et al* 2001). The archaeometallugy guidelines produced by English Heritage states that "the entire assemblage should be visually examined, classified and identified as far as is possible. The finds should be weighed and/or counted and recorded by context. Dimensions should be recorded where appropriate – for example diameters and depths of furnace or hearth bottoms, size of crucibles, diameter of hole in tuyère mouths or blowing holes" (Bayley *et al* 2001, 7).

Therefore, the description of an archaeometallurgical assemblage (primarily waste material and artefacts) based on visual observations should be the first stage of any scientific work investigating ancient metallurgical technologies, and provides the basis for any other scientific probing such as microstructural and compositional analyses (Bayley *et al* 2001). Many publications that have dealt with metallurgical assemblages provide detailed material descriptions and it has become clear that doing this not only allows identification of the associated technologies (e.g. size and shape of furnace – overall process) but can in some cases also inform more specific technological 'chaîne opératoire' processes (e.g. tapping or addition of a flux, etc.). This, in turn informs the choices and actions of past metallurgical practitioners (Bayley *et al* 2001; Gordon 1997; Juleff 1996; 1998; Paynter 2006) allowing for a better understanding of the technologies and operational processes employed as well as the people that made and worked them. This section will outline the methodology employed to visually analyse the archaeometallurgical material collected from the sites surveyed during the Pioneering Metallurgy Project. It will also summarise how this data was treated and analysed to form relevant interpretations about the ancient technological industries of the region.

4.2.1 Pioneering Metallurgy Material Sampling

The material collected during the 2010 Pioneering Metallurgy Project survey primarily consists of technological debris, that is, smelting slags, smithing slags, tuyeres, furnace wall, crucibles, coloured glassy slags, ores, geological material and metallic iron. These are typical of archaeological assemblages associated with iron (smelting) and steel (crucible steel) production as well as refining processes where these metals were consolidated and eventually formed into objects (smithing) (Bayley *et al* 2001). This material was collected from 189 locations in Northern Telangana and forms the basis of this thesis. Refer to chapter 4.1 for the fieldwork and post-survey recording methodology and chapter 5 for a more in depth characterisation of the locations/sites.

The samples were collected from the majority of metallurgical sites surveyed. All were collected from the ground surface and although they are qualitatively representative of the technological material observed at each location, they are not quantitatively representative. In this respect, the material likely represented most metallurgical technologies once in operation at these sites but perhaps did not reflect their full extent or show proportional representation of individual technologies. This was mitigated to some extent by the notes taken during fieldwork on the locations and assemblages visible which gave brief descriptions of the dominant material type. It is also important to mention that the material was only representative of the material visible on the surface and there is a possibility that different residues were buried below the surface which were not observed and therefore not sampled.

The process of sample collection was relatively simple. It involved walking around the location and at the same time as making notes of the metallurgical remains (discussed in chapter 4.1.1), representative samples were selected from the surface. As well as the best preserved samples, a good proportion of material in various states of preservation were taken. Due to the large size of the fieldwork survey team, the collection of materials was usually delegated to one or two people daily, allowing them to concentrate on this important task. The samples taken were put into sturdy concrete bags and labelled with the location identifier where they were found so as to not get them mixed up and avoid confusion at a later stage. Every evening, after a day in the field, the samples were weighed, logged, washed and left overnight to dry.

In order to identify the past metallurgical activities occurring at each of these locations, the archaeological material was subjected to systematic visual assessments. This macro-morphological analysis was achieved in two main phases; the first consisted of an initial classification of recorded material at the fieldwork base in Dharmapuri while the second was a more in-depth examination of a selected sample set taken to National Institute of Advanced Studies (NIAS) in Bangalore. The aim of the first phase was to allow the identification of correlations, comparisons and groupings of shared attributes across the entire collected assemblage by location. This initial classification at the end of the Pioneering Metallurgy Project fieldwork was not used in this study as it was deemed too broad, negating more in depth details which would be required for technological identification. More information on the initial classification can be found in Cox and Haricharan (2011). However, it did allow the material to be sorted and enabled a representative proportion of the assemblage to be selected. Approximately 1/3rd of the samples were taken to NIAS, Bangalore for the second phase of analysis. The aim of which was to record more in-depth information using a narrative approach based on observation of features and comparison with survey-wide material. By studying related location assemblages as a whole and identifying prominent and recurrent features in the material, the technologies and industrial processes producing particular debris types could be identified. Once this was completed, the material typology was formalised allowing the material left in Dharmapuri to be easily incorporated into these material groups. This following section will discuss the methods employed in the more in-depth second phase assessment of the material.

4.2.2 Material Recording and Typology

The material was visually assessed under natural light conditions during the daytime but a bright white artificial light was used during darker parts of the day and night-time. To account for the differentiation in colour perception in these two different lighting conditions, all the material described in artificial light was checked the next day in natural light and necessary corrections made to the descriptions, allowing for greater consistency in the data collected. All visual assessments were made with the naked eye and no magnification tools were used. The first step was to regroup and organise the material into the individual locations where they were found. In order to have a better overview of all the location assemblages, all the material would ideally have been laid out together facilitating material comparisons between each location. However, due to the large quantity of material collected and lack of workspace, the material was visually assessed by location with the material from one location at a time (or a few depending on the quantity) being laid out on the floor. This was done in chronological order from the first location visited 25/02/10 (1) to the last 01/03/10 (10). Each location took between 2 hours and 3 days depending on the quantity of material to assess and the entire assemblage took a total of 10 months to complete.

The second step was to separate the material into broad material types such as tap slag, furnace slag, smithing slag, furnace wall, tuyeres, crucibles, glassy slags, ores, iron and geological. This material was then weighed collectively by type, per location, using electronic scales and the data tabulated in a spreadsheet. Individual fragments were not weighed unless they were exceptionally well preserved and showed distinctive features.

Due to the weight limit of the electronic scales available, all weight measurements below 1000g were taken to the nearest gram while individual fragments in excess of that, were weighed with a larger scale to the nearest 10g. Detailed description notes of the material were then taken whereby morphological aspects such as size, shape, colour, texture, porosity, inclusions, fabric and any distinctive or diagnostic features were recorded (discussed in the sections below). Variations in these morphological aspects were also noted – for example, colour, texture and porosity variation on different parts of a surface. This was done for all material types, in each location.

The majority of the material was fragmentary, with few pieces surviving complete and due to time constraints (with the exception of more complete fragments or those with distinctive features) they were not described and weighed individually but as a location assemblage under the basic material types outlined above. As more material was assessed it became clear that within these types there were significant morphological variations which allowed the identification of sub-types of material (e.g. different tuyere types). As the morphological differences became more defined, the material was recorded and weighed under these sub-types (see chapter 6). In some cases the fragments were very small with no diagnostic features nor original surfaces. These fragments were weighed and recorded as non-diagnostic fragments.

The written descriptions were systemised with clear headings, separating descriptions of different material types and locations. Since all the assemblages from all locations could not be assessed together, this facilitated access to specific material type descriptions when comparing material from one location to another. Another useful comparative method was a comprehensive photographic record. A selection of representative material from each location was photographed by type or sub-type. The methods employed for photographing the assemblages are discussed below. Once all the material had been observed, the information was synthesised by material type and sub-type. Detailed descriptions of each sub-type of material with variations in morphology at location level were created. This document can be referred to in appendix C. Once locations were grouped to form sites (chapter 4.1.3), this appendix was synthesised further in relation to these sites. The most important morphological characteristics of each material sub-type is presented in chapter 6.

4.2.2.1 Measurements

For each type or sub-type, the material fragments were measured. Different measurements were recorded for each material type using a metal rule, to the nearest millimetre. Three measurements were taken for the slag, ore, metal and geological fragments: the length, width and thickness (Figure 4.2). In the case of the ores, metals, amorphous slag (including glassy slags) and geological fragments only the maximum length measurement was taken. For the other fragments their lengths, widths and thicknesses were determined by the orientation of the fragment. In the case of the slags, the top and bottom surfaces usually remained partially intact allowing their thickness to be measured. The length and width were then taken at the widest points. Some well-preserved furnace bottom slag cakes were also collected which allowed the furnace inner diameters to be estimated (chapter 6.2.2).

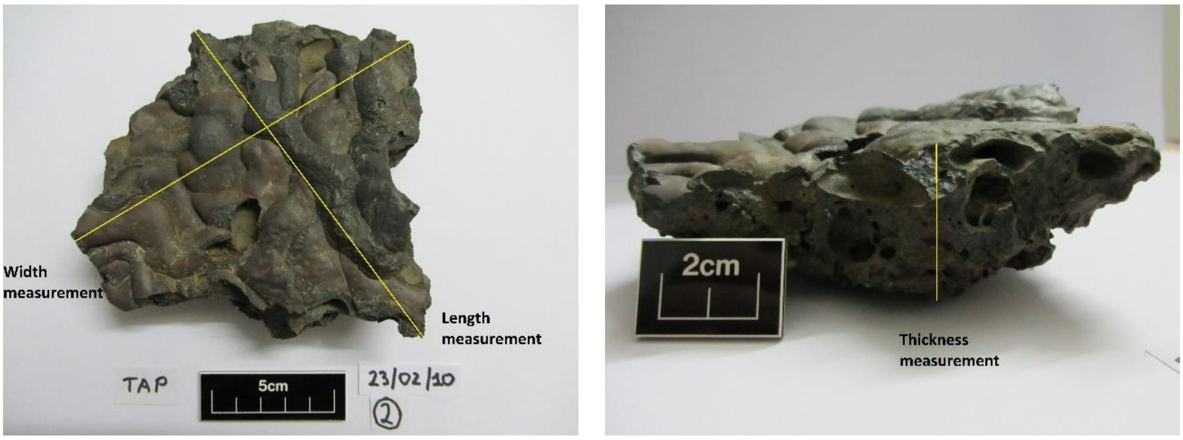


Figure 4.2 - Measurements taken for the slag fragments. Similar measurements taken for the ore, metal and geological fragments.

For the tuyeres, their length, wall thickness and inner diameter were measured. Their length was measured from the rim to nozzle end (or to the surviving end), the minimum and maximum wall thicknesses were measured to give a thickness range and their inner diameter was measured at the rim and nozzle end (or the surviving end - Figure 4.3). However, in most cases the tuyeres did not have a complete circumference remaining so the inner diameters were estimated through their surviving curvature using a rim chart to the nearest 5mm (chapter 6.2.5). The length, wall thickness and height were also measured for diagnostic furnace lining fragments while just a maximum length measurement was taken for the non-diagnostic examples. For the furnace base fragments, a thickness measurement was taken at the base and another at the furthest surviving upper portion of the wall (Figure 4.4). Some curved fragments were also preserved enough to estimate their internal diameter with a rim chart to the nearest 5mm (chapter 6.2.4). The crucibles were subject to more measurements than any other material. Where possible their external height was measured from the base to the top of the lids; their minimum and maximum wall thickness; the internal chamber height and diameter as well as the height (from the internal base) of the black glassy slag fin present on most fragments (Figure 4.5). From these measurements it was then possible to estimate the size of the resulting steel ingot. However, many fragments were poorly preserved and some of these measurements could not be taken (chapter 6.2.6).

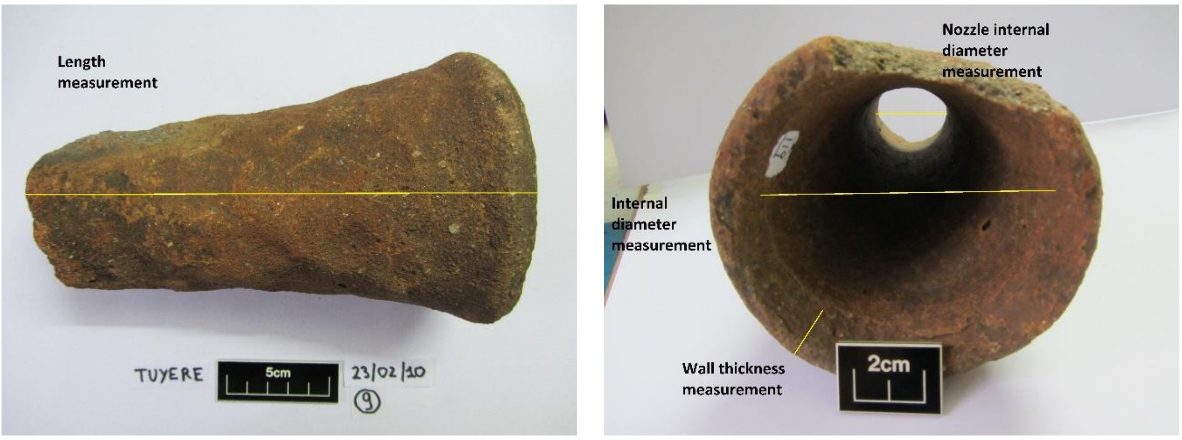


Figure 4.3 - Measurements taken for the tuyere fragments.

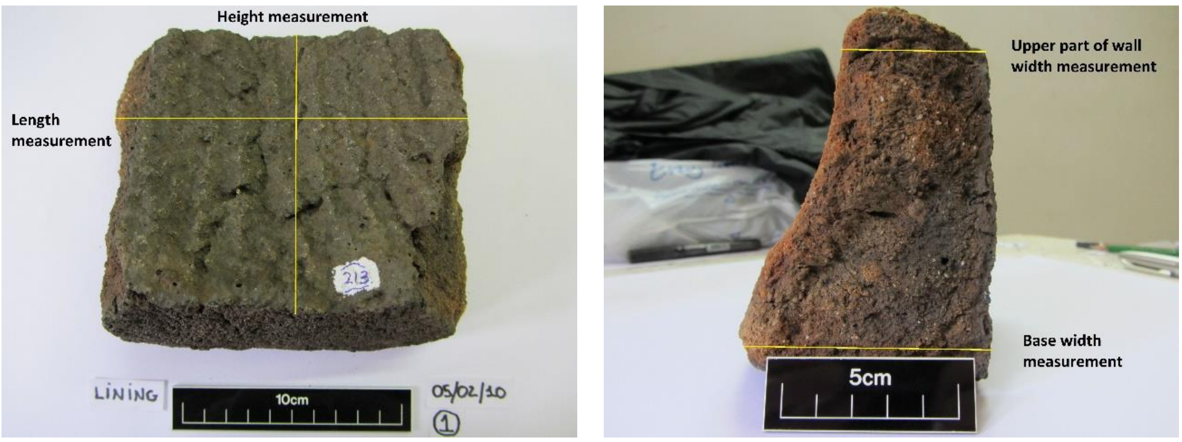
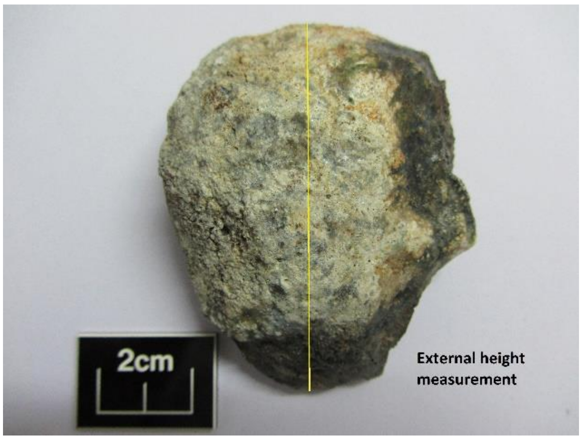


Figure 4.4 - Measurements taken for the furnace lining base fragments.



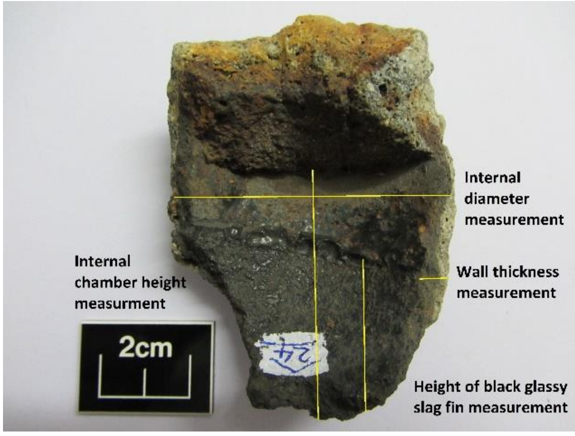


Figure 4.5 - Measurements taken for the crucible fragments.

4.2.2.2 Shape

The shape of each material fragment was described as this can inform the processes that formed them. Each material type had different shapes, and terminologies were adopted to describe them. General descriptive terms such as curved, rounded, angular, flat, undulated, rippled, agitated were used. On a more material specific basis, the shape in profile (plano-convex, concavo-convex, etc.) and plan (circular, elongated, etc.) of the slag fragments were recorded. The general shape of the tuyeres were noted such as tubular or tapering as well as specific features such as flaring, flattened or rounded rims. The identification of curvature or flattened bases was especially important with furnace lining fragments, while the shape of the crucibles formed a large part of how they were characterised (typology), e.g. the shape of their lids (domed or conical) as well as their bases (rounded or flat). Some material fragments had no specific shape. This is especially true of some furnace slag fragments as well as some non-diagnostic furnace lining, ore, geological and metal fragments, and in these cases they were described as amorphous.

4.2.2.3 Colour

Colour was another important characteristic which was recorded. The colouration of all material fragments was described. This was done visually and, although standard colour charts were not used, the descriptions used were appropriate to archaeology standards (e.g. dark brownish-red). In order to account for the broad spectrum of colourations and the contribution of surface texture, these colour descriptions were often preceded by a descriptive term such as dull, shiny, metallic or glassy. The variation of colour across individual fragments was also recorded. On most slag fragments, for example, there was a dominant colouration, usually the dark greyish-blue of typical slag but many had surface patches differing in colour. For the ceramic material, colour was used to infer degrees of oxidisation and reduction. For the most part the more oxidised areas of the ceramic material were an orangey colour while the more reduced parts were of a darker grey colour. This allowed some interpretation of how these fragments were fired and gave information on how and where they were placed in relation to the fire, which was presumably inside the furnace or hearth.

4.2.2.4 Surface texture

The extent of porosity and surface texture was also described. This was especially relevant to slag fragments and vitrified ceramic surfaces on furnace lining, tuyere and crucible fragments but also some of the ore, geological and metal fragments. Porosity was assessed visually by an estimation of the approximate surface area covered with voids. Fragments or surfaces with <2% of voids were described as solid; 2-10% as low porosity; 10-25% as semi-porous; 25-40% as porous and >40% as very porous. The shape of the porosity was described; whether spherical, globular, elongated (flattened), networked or angular. Voids were also measured and a maximum value was usually given to the nearest millimetre. The degree of roughness (smooth, low rough, medium rough, rough and very rough) was determined by how the surfaces felt to the touch. The fragments generally ranged from smooth, where surfaces were flat with no or rounded protrusions, to very rough, where large sharp protrusions were present. In some cases, surfaces had very small protrusions of varying sharpness which required a different terminology from the above. These were described as low, medium and coarse sandpaper texture (roughly equivalent to sandpaper grit sizes 600, 240 and 80 respectively). Surface topography was also described for the slags and vitrified surfaces, such as the size of the projections, their shape (pointed, sharp, rounded, etc.), completeness (broken, chipped, abraded, etc.) and any diagnostic patterns such as evidence of flow (rippled, globular tendrils, etc.).

4.2.2.5 Ceramic fabrics

The tuyere, furnace lining and crucible ceramic fabrics were described. The degree of fabric coarseness was determined visually depending on their geological (quartz) inclusion content. Fabrics with <2% inclusions were described as fine; 2-10% inclusions as low coarse; 10-25% as medium coarse; 25-50% as coarse and >50% as very coarse (Figure 4.6). Inclusions were measured and a maximum, to the nearest millimetre, as well as an average size range was recorded. Wherever possible, inclusions were identified and described without the use of magnification (quartz, slag, organic, etc.). However, some of the organic material was either too small or too degraded (leaving only voids or impressions) to be identifiable at macroscopic level. Future microscopic examination of these fabrics may reveal more on their composition. Inclusions found in the slag fragments were also described and measured in the same way.

Fine Low Medium Coarse Very coarse

Figure 4.6 - Examples of the different levels of ceramic fabric coarseness.

4.2.2.6 Features

Distinctive or diagnostic features observed on the material fragments were recorded as these may give clues on how they were made or formed. Tool-marks were occasionally identified on slag fragments, in the form of regular holes or impressions (chapter 6.2.2) while finger-marks were present on some ceramic material. Tong-marks were also identified on many crucible lids (chapter 6.2.6). Of special interest, were marks or impressions left from technological manufacturing processes such as slip striations on the interior (concave) surfaces of the tuyeres (chapter 6.2.5) and smoothing marks on the interior of the crucibles (chapter 6.2.6) or furnace lining surfaces. Linear impressions (mostly vertical) were also identified on the interior surfaces of some furnace lining fragments, while rounded clay coils were seen on others (chapter 6.2.4). All these features were described and where necessary, measured by length and width. When the orientation of the material fragment was known, the orientation and location of the impressions was also noted. In a few cases, there were tuyere remnants still embedded in larger furnace wall fragments. Their positions were recorded, such as their angle in the furnace wall, how much they protruded into the interior and on the exterior of the furnace, and how far up the wall they were placed (chapter 6.2.5).

4.2.2.7 Magnetism

All material fragments were tested for magnetism with a common handheld magnet and the degree to which they were magnetic recorded, i.e. not magnetic, low, medium and high. Sometimes only small areas/patches of larger fragments were magnetic so these were described and their location documented. The location and size ranges of adhering metallic prills commonly found on the interior surfaces of crucibles were also recorded.

4.2.2.8 Photography

The last step of the visual assessment process was to photograph the material. After all the material from one location had been weighed and described, it was photographed. Not all fragments were photographed but a good representation of the assemblage from each location was selected. Once again, smaller fragments were not photographed individually but with other fragments of the same type and sub-type. The larger fragments and those with distinct features were photographed individually. To gain good contrast between object and background, the material was placed on an A3 sheet of white paper (on a desk). A photographic scale was included in each photo as well as a location number label (e.g. 01/01/10 (1)) and material type label (e.g. furnace slag). Material types were photographed from varying angles depending on their state of preservation, shape and orientation. The top, bottom and side profile of diagnostic slags and geological fragments were photographed. Since the tuyeres were primarily cylindrical they did not have a particular orientation so they were photographed on two opposite sides and another photograph was taken facing the rim opening. The top, bottom, internal and external surfaces as well as the side profile of the furnace lining bases were photographed. For the smaller, less well preserved furnace lining and tuyere fragments as well as all the crucible fragments, the internal and external surfaces were photographed. Since their orientation was unknown, the iron, ore and non-diagnostic or amorphous slag fragments were photographed on two opposite sides. It is important to mention that fragments were photographed so that they occupied a central position in the photo with all of their edges visible. However, some of the special features found on the materials (outlined above) were photographed at a closer range in macro-mode, so as to capture greater detail. A good selection of material photographs are in appendix C.

4.2.3 Data Processing and Analysis

The large body of descriptive data combining morphological variation at location-level (collected as outlined above) is presented in appendix C while a synthesised version assessing material sub-type morphology at site-level is presented in chapter 6. This section will outline how the assemblage was quantified (chapter 6) and how specific technological groups were identified at site-level (chapter 7).

4.2.3.1 Quantification

The material weights for the whole assemblage were organised into a Microsoft Excel spreadsheet, with rows representing sites and columns representing material types (Table 4.4). The spreadsheet ordered material weights at site-level (appendix B) allowing the entire assemblage to be quantified in relation to the sites. The assemblage was first quantified by total weight of both general material types (e.g. tap slag, furnace slag, tuyere, crucibles, etc.) and individual sub-types. However, since the weights are not proportionally representative of the material present at each site, they only serve as a guide to the material collected. More significant, was the second quantification, which was by proportion of sites in which each material type and sub-type occurred. This is a better representation of how common and widespread particular sub-types of material were across the survey. For both sets of data, pie charts were created in excel to present the results and support the discussion (see chapter 6).

Table 4.4 – Example of Excel spreadsheet for quantification of assemblage.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1			Tap Slag					Furnace Slag															
2	Site	Loc.	TS1	TS1.1	TS1.2	TS2	TS3	FS1	FS1.1	FS1.2	FS1.3	FS1.4	FS1.5	FS1.6	FS2	FS2.1	FS3	FS4	FS5	FS5.1	FS5.2	FS6	ND
89	PM110	A	1213						2490												130	81	
90	PM111	SE-A		650		2802			390							240						200	
91	PM112	F	6500	990		2700	120	13460	480										2120			110	
92	PM113	SE-BS	18426			490											340			440		180	
93	PM114		6400																				
94	PM115	SE-A	2638																	1160			
95	PM116	A	4798		1430	1040		760															
96	PM117	A	2613														1170						
97	PM118	A	750	1410		863										1200			7530	430		100	
98	PM119	SE-BS	1450								3330						190					3260	
99	PM120	SE	855												80								
100	PM121		1270														280						
101	PM122																						
102	PM123	SE-BS	2328	1290																			
103	PM124	S	290			170														150			
104	PM125	SE	6170					5250							1230	1310	200						
105	PM127	SE-A	971	3160				870								520		414			61		
106	PM128	A	1562	1630				10050	110	10050				13590		4150							
107	PM129	A	1370				1740			1480						250	1120						
108	PM130	A-BS	1454									2310						135	520	410			
109	PM131	S	300						2240						551								
110	PM132	SE-BS	2640		1350		848	8670	950							430						660	
111	PM133	SE-BS																					
112	PM134	A	1400	1189	817	6569			1063							65			2150	980		80	
113	PM135	A=BS	2060																				
114	PM136																						
115	PM137	SE-A	490		530																		
116	PM139		600					6640															
117	TOTAL		277745	70048	25930	82958	14880	144782	39249	102291	32543	7204	9070	13590	16680	61450	30254	3826	84723	29741	4372	16981	6668
118	No of sites		85	42	16	32	15	31	16	18	4	5	1	1	28	30	28	10	36	22	8	21	10

4.2.3.2 Technological Resolution

The material types and sub-types recorded at each site are a direct reflection of the metallurgical processes once in operation. Therefore, technological resolution is achieved by the identification and analysis of these materials. By assessing material sub-type presence on sites and identifying which materials occur together, it is possible to identify groups of metallurgical processes or practices.

A first attempt at achieving technological resolution involved assessing the assemblage using a statistical approach. Since the weights were not proportionally representative of the materials present on each site, the excel spreadsheet discussed above was transformed into absence-presence data. All occurrences of material sub-types where recorded as 1, irrespective of weight. Materials absent from sites were recorded as 0. The data was not given any weighting, consisting only of 1's and 0's for presence and absence. This database was then assessed using multiple correspondence analysis (MCA) with R programming language. In MCA, the distances between two data points are assigned in terms of Chi-squared measures. Based on this, an Eigen value decomposition is conducted, which essentially tells us which orthogonal directions indicate most change/variations between sites. A number of Eigen vectors were formulated based on the variation of material presence on sites (Alma Rahat, Computer Science, University of Exeter, pers. comm. 2016). The most significant of which were plotted on a scatter graph to identify potential trends. However, all efforts were non-conclusive and did not reveal any significant site groupings or trends. Several reasons for this are possible.

First and foremost, the data gathered during the initial visual examination of the material was not collected with statistical analyses in mind. The majority of the information was qualitative (detailed descriptions) and not optimised for statistics. The creation of material sub-types based on shared morphological attributes helped to systemise the data but the sub-types remain broad. Within each sub-type there are significant morphological variations which have been assessed in appendix C. Therefore, it is likely that individual sub-types are not just representative of one technological practise but of several. This variation in sub-type morphology could not be assessed statistically. It is also important to note that a large quantity of the technical ceramic material recovered (furnace wall and tuyeres) was fragmentary, retaining few original surfaces. Hence, much of this material was non-diagnostic, further complicating technological resolution. Another dimension which could not be assessed statistically are the site descriptions (from diary entries – see chapter 4.1) which contain much information on the dominance of certain material types and sub-types.

In addition to the way in which the assemblage was recorded, the method in which it was initially sampled from the sites also hinders technological resolution via statistical methods. All material was collected from the surface, and on the majority of sites, the full extent of material residues present was possibly not observed and collected. A large proportion of this material was probably buried. For example, only few sites have a good representation of all major types of material (slags, furnace wall and tuyeres). Most have significant gaps, either with good representation of one type of material and little evidence of others, or very sparse evidence of all types. This makes it difficult to identify materials associated with specific technologies or processes. Another issue, is the lack of specific context. Since the majority of the material were surface finds from disturbed sites, they have no stratigraphic or temporal context. To add further complexity, the mixed material probably represented more than one process making their identification difficult. Therefore, the methods in which the assemblage was collected from the sites, the relatively poor preservation of some of the materials and the manner in which it was visually recorded, prevented satisfactory results from statistical analyses. Due to this, the results of the MCA are not provided in this study and will not be discussed further.

Nevertheless, the large set of qualitative data from the visual observations of the material and descriptive field notes are significant and allow the identification of some trends. The only method which would account for all forms of evidence and their limitations was a systematic manual assessment of the data. This was done on three levels. First, sites with similar materials were identified. This was done with the aid of the sorting tool in Excel, allowing sites to be sorted by presence of certain material sub-types. During this process it became clear that some materials preferentially occurred together, permitting more complex customised sorts of multiple sub-types of material. This allowed the identification of the main iron smelting and crucible steel technological groups, as well as sites with distinctive or unusual materials. Second, was the refinement of these major trends by assessing variation within these technological groups. A review of the detailed material (appendix C) and site descriptions (appendix A) provided an extra dimension with which trends could be assessed. In some cases, it allowed the identification of more specific groups. Lastly, technological groups were finalised by checking the photographic record of each site to confirm identified trends.

This was a lengthy procedure but the most effective in considering all forms of evidence, the majority of which was qualitative. The technological groups were then compared to the site types and descriptive categories such as site location and setting. Particular attention was paid to assessing trends between the materials present on sites with and without crucibles as well as settlement and forest sites (chapter 7.4).

4.3 Micro-structural and Compositional Analysis of Material

Compositional and micro-structural analyses of the archaeological material previously examined macro-morphologically, can add significant knowledge about the processes which formed them. They are useful in understanding how the technological structures (furnaces, crucibles and tuyeres) where built, for example, what kinds of raw material they are made of and what processes they have undergone before and during use (i.e. drying, firing, etc.). In addition, the scientific analysis of the slags, ores and iron can elucidate the raw materials used during smelting and to a certain extent inform on the *chaine operatoire* processes of iron smelting and crucible steel production (i.e. temperatures reached, added flux, etc.). The examination of the iron fragments recovered and the prills found lining the interior surfaces of the crucibles will enable an estimation of their carbon content as well as the identification of minor elements present. This will, in turn, inform the final products and enable the identification of what was produced (iron or steel). Above all, the compositional and micro-structural analysis of the material will provide an additional dimension to support or refute observations made during the macro-morphological analysis. Different material types identified during that process can be compared micro-structurally and compositionally, enabling differences in manufacture and process (if any) to be identified.

4.3.1 Sample Selection

The first and ultimately most important step in scientific analysis is the selection of suitable samples. These must be chosen to answer more precise specific questions about the materials and technologies under study. Due to the large array of material types identified during the macro-morphological analysis and the limited resources (available sample preparation and analytical machine laboratories) as well as time constraints, only a limited number of samples could be chosen for scientific analysis. Priority was therefore given to the main focus of this study and the one which may have the greatest academic impact, that is, the crucibles.

The samples consisted of 45 examples, representing a good selection of the three types of crucibles (C1, C2 and C3 – see chapter 8) as well as associated materials like the green and black glassy slags (GS1 and GS2). The samples were chosen not only to represent the main crucible types but also to represent the main crucible steel production sites, taking into account the quality of the archaeological remains and their spatial distribution. Wherever possible, they were selected from better preserved sites, while material from secondary deposits were avoided. The coloured glassy slag samples were only taken from sites where crucibles had also been selected. The crucible fragments were carefully chosen so that maximum information could be extrapolated from them. Priority was given to better preserved examples which retained their three major compositional layers: the coarse external vitrified ceramic lining, the fine main crucible body fabric and the black glassy internal fin. In addition, examples abundant in metallic prills were also selected in the hope that these could be sectioned and analysed. Since the majority of the crucible fragments where body sherds without lids, a good range of separate lid samples were also selected for each crucible type. Lids were only selected from sites where crucible body fragments were also taken. Each selected fragment was individually photographed, as described above (chapter 4.2).

4.3.2 Sample Preparation

The sample preparation method adopted for optical and scanning electron microscopy (SEM) analysis was resin-mounted polished sections with one flat surface polished to 1 micron or finer. This sample preparation process was done following standard procedure (Scott 1991). Cutting and carbon coating was done in the Earth Sciences Department while mounting, grinding/polishing and etching was done in the Material Engineering Department, both of the Indian Institute of Science (IISc), Bangalore. Work was done in India because samples could not be taken out of the country.

The first step was to cut the samples so that a flat, cross-sectional profile was created. The samples were hand cut using a Struers rock saw fitted with a diamond cutting blade. Cut samples were taken to fit 1.25” diameter mounting pots. The cuts were made in order to preserve the maximum amount of material. Wherever possible, a good section of the three main material layers (on the body sherds) discussed above was cut (Figure 4.7), in the hope that this would yield information on their construction and use. A similar approach was taken for the lid fragments, with cuts spanning from their edge through to their centre. All external and internal surfaces (of both body and lid fragments) were preserved so that elements of the external vitrification and internal melting of the charge could be examined. In a few cases, on larger crucible fragments where parts of the crucible lid still remained attached to the body, the samples cut had to be halved and fitted into two moulds. Typically, the cut was made between the body and lid sections so that each part could be mounted separately.

Due to the apparently more consistent composition of the green and black glassy slag fragments, the location of the sample cuts was not as crucial. For the green glassy slags with whitish-grey inclusion elements, care was also taken to get a good representation of this material. The cut made on each selected material sample was recorded on printed photographs, by drawing a line with an arrow pointing to the cross-sectional surface to be polished and analysed. These were later digitised in Microsoft Paint (Figure 4.7) and can be referred to in appendix D.1. All cut samples were then given simple numeric sample numbers starting from 1 and a table was created associating sample number to material type, location and site numbers so that there could be no confusion as to their provenance (Table 8.1 - chapter 8).

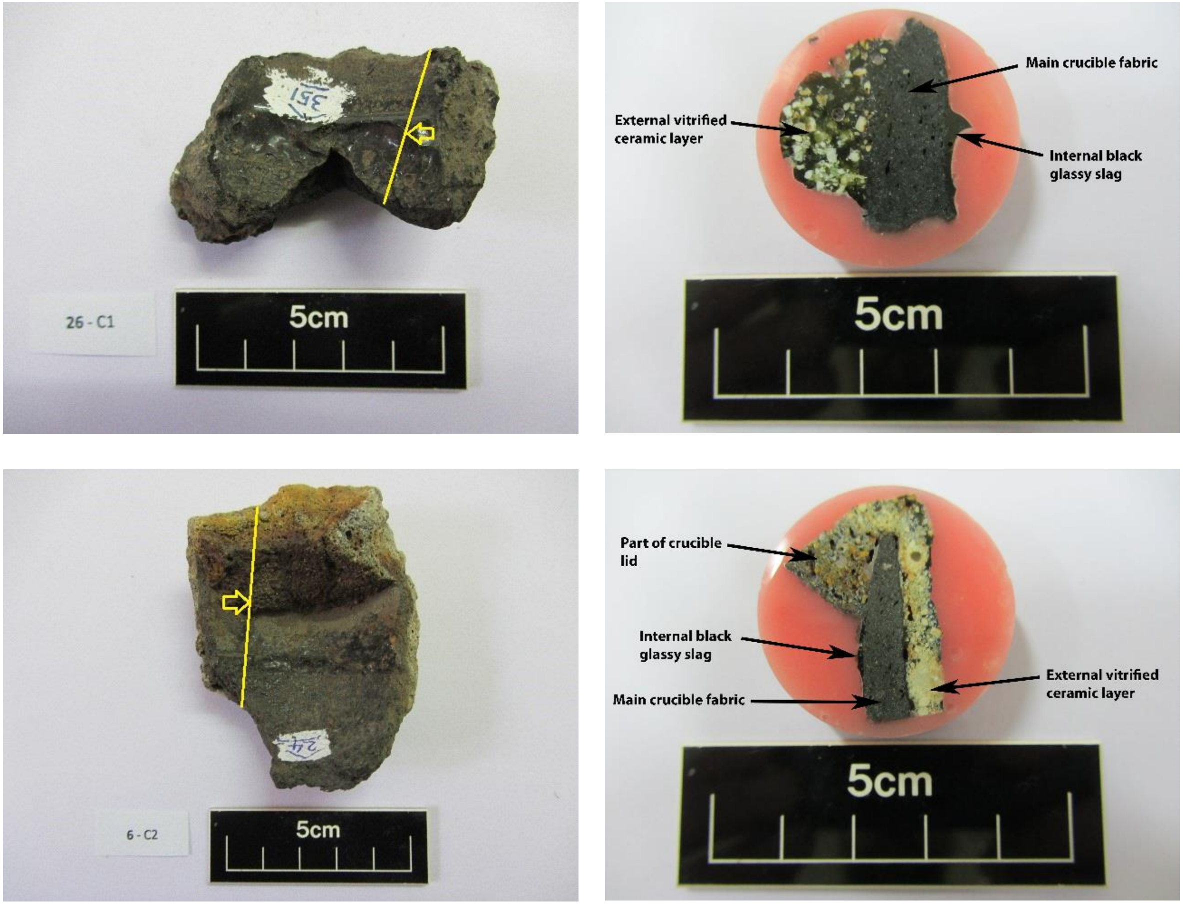


Figure 4.7 - Sampling examples with marked cuts (left) and the cut cross-section mounted in resin (left) showing the main three material layers.

Once the samples were cut, they were dried with a hairdryer and left to air dry at least 48 hours to limit oxidisation of metallic prills. The cut samples were then placed face down into Beuhler 1.25” mounting pots and resin was poured on top of them until the entire sample was covered. Due to the unavailability of low viscosity specialist epoxy resin, a pink-coloured acrylic dental resin was used. The mounted samples were left to cure for a minimum of three hours and then taken out of the moulds. Due to its viscous properties, the resin caused a few problems and several trial attempts were necessary to find the best method of mixing and pouring. Large air bubbles regularly formed inside the resin and were trapped while hardening. In some cases, these air voids were present on the flat surface to be ground and polished. In addition, the resin was too viscous to adequately fill the small voids in the most porous samples. These problems were managed by gently tapping the filled pots on the work bench, allowing trapped air bubbles to be released from the resin. The most porous samples were also carefully coated with additional resin to fill as many surface voids as possible. Sample numbers were written on each sample with a permanent marker immediately after removal from the moulds.

After mounting in resin, the samples were ground and polished. They were ground on a Bainpol ChennaiMetco grinding-polishing machine with a 200mm diameter rotating wheel. Wet and dry silicon carbide paper sheets were cut to fit onto the wheel and the samples were ground by placing the flat surface onto the rotating paper (lubricated by a constant stream of water) and applying equal pressure on the back of the sample. Various grades of silicone carbide paper were used, starting at P100 and systematically ascending to finer grits P320, P600, P1000, P1500, P2000, P2500 and P3000. The samples were kept still on the grinding wheel (grinding in only one direction for each grade) so that the surface scratches were clearly visible and unidirectional. The samples were then rotated 90 degrees on the next grade of paper and ground until the previous, coarser scratches where completely removed. On the finer papers, a high powered jeweller's loupe was used to survey the surface scratching. On the final grade of paper (P3000) the samples were gently moved in a figure of eight motion and slowly rotated so as to create a finer and more even finish before the final polish.

Final polishing was done on a Metatech Metapol DC II polishing machine also with a 200mm diameter rotating wheel. A fine synthetic cloth was placed on the rotating wheel and a small amount of diamond polishing paste (DD-TEC 0-1/2 ~ 1 micron) was applied. Kerosene was used as a suspension and sprayed onto the cloth to act as a lubricant when necessary. Similar to the final paper grade, the samples were gently pressed onto the cloth and moved in a figure of eight motion while rotating them so as to remove all scratches. Each sample was polished for at least 10 minutes and then checked using an inverted stage optical microscope (Zeiss Axiovert 200M) to make sure there were no visible surface scratches at magnifications up to x250. The samples were then thoroughly dried with napkin paper and placed into a covered plastic box to prevent exposure to external impurities such as dust.

Several issues had to be overcome during the grinding and polishing process. Most samples were very porous and the lack of vacuum impregnation as well as the use of a viscous resin meant that the surfaces being ground and polished were ridden with many small voids. These voids had a tendency to accumulate debris and weakened the structural integrity of the polished surface, sometimes causing small chunks of material to detach. In some instances, this caused samples to be ruined and the grinding and polishing process had to be restarted. For the most part though, small debris released from these voids caused numerous large scratches on the samples. This was counteracted by thoroughly washing each sample after each grade of paper and polish under a running tap (at high pressure) while wiping the surface with a cotton bud. This greatly limited scratching from trapped material but care was still taken at every stage to remove all the previous scratches. This was a lengthy process but most samples were successfully polished with very few minor scratches. Each sample took an average of 2 hours to grind and polish.

Two samples had large metallic prills which had a tendency to oxidise within a few hours of being polished. Due to the metal being softer material than the ceramic matrix, the 1 micron finish was insufficient and small scratches could still be seen at high optical magnifications. These two samples were therefore polished to approximately 0.05 micron with colloidal silica in the same manner as the 1 micron finish. To combat the fast oxidisation of the prills, the samples were etched immediately after polishing with 2% nital (mixture of nitric acid and ethanol). A small amount of the solution was poured into a petri dish and the samples were dipped (face down) into the dish for several seconds at a time. They were then rinsed with water, dried with napkin paper and hairdryer. After each etching attempt, the two samples were checked using an inverted stage optical microscope (Zeiss Axiovert 200M) to see if the prills had been sufficiently etched. The process was repeated until the prill microstructures could be clearly seen.

After polishing, the samples were carbon coated so that they could be analysed in a scanning electron microscope (SEM). The machine used was a Quarum Q150R E carbon coater. One sample at a time was placed in the glass chamber and a high purity carbon string was fitted between two electrodes at the top of the chamber. The chamber was placed under vacuum and the current increased to vaporise the carbon string which coated the samples with a ~20nm thin carbon film. Due to the high porosity of the samples, the machine took some time to create a suitable vacuum pressure in the chamber and each sample took 10-20 minutes to carbon coat.

Unfortunately, due to time constraints and availability of the analytical machines (optical and analytical), only about half of the samples selected and prepared could be analysed (26 samples were completed out of the 45 originally selected). In order to provide a more complete analysis, samples of only one material type were prioritised, the crucible main bodies, in the belief that they would reveal the most about the crucible steel manufacturing process. All geological, individual glassy slags (black and green) and most lid samples were omitted from the final analysis.

4.3.3 Micro-structural Analysis

The metallic prill microstructures were observed before carbon coating using a Zeiss Axiovert 200M inverted stage optical microscope fitted with a camera. Magnifications of x50-500 were used to survey the etched surfaces of the prills. Micrographs of the surfaces were taken with the Axio Cam Hrm using Axiovision software. General micrographs were taken of the overall microstructure at x50-100 magnification, while interesting features requiring greater detail were taken at magnifications of x200-500. Before each micrograph was taken, care was taken to assure that the image was focused and that contrast and brightness were suitable. All images were taken with a measurement scale at the bottom to provide a size reference of the microstructural phases. Detailed notes were also taken for each sample.

Microstructural observation of the crucible fabrics (the coarse external vitrified ceramic lining, the fine main crucible body fabric and the black glassy internal fin) were undertaken after carbon coating, using a FEI Quanta 200 scanning electron microscope with FEI's xT Microscope Control software. Due to the limited machine time available, two SEMs were used (both identical) in two different labs – Advanced Facility for Microscopy and Microanalysis (AFMM) and Material Engineering, both part of IISc, Bangalore. A synthesised table of the basic microstructural observations of each sample is given in appendix D.2. In total, approximately 30 hours of SEM imaging time was possible over a two and half month period. All microstructural surveying and imaging was done using the back-scattered electron detector – the brightness of each region being related to the average atomic number of that region. Machine settings were kept constant at an accelerating voltage of 20Kv and spot size of 4.5nm with the samples set at a working distance of 10mm.

Phase identification was done in the same SEM by spot analysing different mineral phases. Analyses were taken using EDAX and the data de-convoluted using the EDAX Genesis software. The analyses were not recorded but used for identification purposes during the observation of the samples' microstructures. For this, the accelerating voltage was increased to 25Kv and the spot size increased to 5nm as this provided the best counts and dead-time for the material.

4.3.4 Compositional Analysis

The next step after microstructural observation was the elemental analysis of all samples. Due to restrictions on SEM machine time, the elemental analyses were not undertaken in the laboratories mentioned above but at the Centre for Nano Science and Engineering (CeNSE) in IISc, Bangalore. This enabled all the samples to be analysed with the same machine, limiting any potential data inaccuracies that might arise by using different equipment. A total of 24 hours machine time was negotiated over a period of 6 weeks. All samples were analysed in a Zeiss Ultra 55 SEM, fitted with an energy dispersive X-ray spectrometer (EDS – Oxford Instruments X-Max SDD 50nm^2). The navigation software used was Zeiss' SmartSEM while Oxford Instruments INCA software was used for EDS spectra collection and analysis. Analytical parameters were kept constant at an accelerating voltage of 20Kv and beam aperture of 30 micron with the samples set at a working distance of 7-8mm. Due to in-lab rules, the author was not allowed to control the imaging navigation. This was controlled by a specialist technician (Mrs Sampada Gurav) who could be directed to the areas needing analysis. At the same time the author had control over the EDS (INCA) software.

The data was collected through bulk analyses at magnifications between 100x to 1000x depending on the size of the crystalline structures and material layer as well as the homogeneity of the material. Each spectra was collected for 60 seconds with a processing time of 6. An average composition was determined by taking the mean of 3 to 5 bulk readings per material type. The more homogenous the sample the fewer readings were required to reach a reliable average, however, due to time constraints only a maximum of 5 bulk analyses could be taken per material type. Areas analysed were carefully selected to show a good representation of crystalline phases while areas of unusual heterogeneity (corrosion or contamination) or ones making up a minor percentage of the overall sample were avoided. Areas with unusually large voids or excessive porosity were also avoided.

Compositions for the crucibles (all material layers) were calculated assuming that all elements were present as oxides (stoichiometric). This included the metallic prills present in some of the material layers. Although a large part of the Fe content was likely to be in metallic form, it was recorded as an oxide to facilitate quantification and comparisons between samples. In addition, compositions were normalised to 100wt% to allow comparisons between samples with varying degrees of porosity. The SEM-EDS has a detection limit for most elements of ~0.1wt%. The data was rounded to one decimal place while compositions below the detection limit of the measured element were labelled BDL (below detection limit). Any element below the detection limit in all samples is not displayed in the data tables. The elements analysed for the crucible fabrics were Na, Mg, Al, Si, P, S, K, Ca, Ti, V, Cr, Mn, Fe while Co, Ni, Cu, Zn, As, Zr, Nb, Mo, Sn, Sb, Ce, W, Pt and Pb were also sought for in the iron prills.

A crucial aspect of using quantitative elemental data is the verification of its reliability. In order to do that, standards of known composition are examined in the same SEM using the same operational parameters. Unfortunately, no suitable standards were available which were close to the elemental composition of the crucible fabric layers, which means that no verifiability data was obtained for Na_2O, P_2O_5 and SO_3 contents. Nevertheless, two standards were selected which contained compositions as close as possible to the majority of the material analysed in this study. The standards are the almandine garnet and biotite from Astimex Standards Limited (MINM25+53 + FC Serial LR). Three areas in each standard were examined and the results compared to the reported values (Tables 4.5 and 4.6). This confirms that the data for MgO, Al_2O_3, SiO_2, K_2O, CaO, TiO_2, MnO and FeO reported in this study are accurate. However, there does appear to be some overlap between the SiO_2 and FeO values recorded, showing a lack of consistency the higher the FeO content, especially above 10wt%. Since the FeO content of the crucibles tend to be below this, it should not be of too much concern.

Table 4.5 - Analysis of the almandine garnet standard 2 from Astimex Standards Limited (MINM25+53 + FC Serial LR) with the mean and reported results.

No.	MgO	Al_2O_3	SiO_2	CaO	MnO	FeO
DL	0.1	0.1	0.1	0.1	0.1	0.1
1	10.6	21.9	36.9	3.9	0.5	26.2
2	10.6	21.7	37.2	3.9	0.5	26.2
3	10.4	21.9	37.0	3.9	0.6	26.2
Mean	**10.5**	**21.8**	**37.0**	**3.9**	**0.5**	**26.2**
Std. dev	0.07	0.14	0.18	0	0.05	0.04
Reported	**10.7**	**22.05**	**39.19**	**4.2**	**0.59**	**23.27**

Table 4.6 - Analysis of the biotite standard 7 from Astimex Standards Limited (MINM25+53 + FC Serial LR) with the mean and reported results.

No.	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	FeO
DL	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1	19.8	14.8	37.1	10.8	0.0	1.7	0.2	11.5
2	19.8	14.8	37.1	10.5	0.2	1.8	0.1	11.7
3	19.5	14.8	37.3	10.6	0.1	1.8	0.1	11.6
Mean	**19.7**	**14.8**	**37.2**	**10.6**	**0.1**	**1.8**	**0.1**	**11.6**
Std. dev	0.15	0.02	0.10	0.18	0.05	0.05	0.05	0.12
Reported	**19.52**	**15.13**	**38.72**	**9.91**	**0.1**	**1.77**	**0.04**	**10.72**

4.3.5 Data Processing and Analysis

This section will briefly describe how the scientific microstructural and elemental data was collected, stored and manipulated for analysis.

4.3.5.1 Microstructural Data

Microstructural imaging was done as described above and in addition to collecting images, detailed descriptions of the microstructural phases and general nature of the four main crucible fabric layers analysed were taken. The main focus of the observation and description notes was on the identification of mineral phases, inclusions, porosity and recording of any special features. It is important to mention that no quantitative data was collected, with the majority of the data focusing on detailed qualitative descriptions of microstructural observations. Generally, each material layer was looked at individually, starting with the exterior coarse layer, then the lid, the main body and finally the internal glassy slag. Aspects such as the types of mineral phases, nature of porosity and inclusions were described with their location within the sample, size, shape and relative quantitative proportions accessed. The measurements of mineral phases and voids were calculated using the measuring tool in the FEI's xT Microscope Control software. In general, a few of the features (phases and voids) were measured giving an approximate average size for the feature, but measurements of the largest examples found were also taken to give a maximum. Due to the lack of machine time, no mapping tools/software could be used during analysis. This means that quantitative proportions of individual phases and voids or porosity could not be accessed.

These primary observations were noted on a form (Figure 4.8) which included the sample number, sample provenance, material type and date analysed, to keep track of all data recorded, avoiding accidental data loss or mix-ups. In addition to this, the machine used and operating specifications were noted, with the majority of the form left for the detailed micro-structural descriptions (Figure 4.8). Having a standardised form allowed more consistent data to be obtained and limited inconsistencies in data collection which may affect later interpretation of the findings. The forms were then scanned for safe keeping.

Date:

Sample No:	Location:	Site:
Material Type:		
Analysis Machine:		
Machine Settings:		
Microstructure:		

Figure 4.8 - Example of form used to record the microstructural observations in each sample.

In order to facilitate data processing, all core data was transferred into a large table. This table incorporated all major observations of different material layers found within each sample and is given in appendix D.2. The location, size, shape and proportion of mineral phases and porosity are laid out by material type and sample number. This facilitated the comparison of all observed microstructures between samples. Since no truly quantitative data was collected, the results were not standardised for statistical use. The results and observations of each sample did not vary enough from one another to merit more complex analytical methods. For the most part, all samples were microstructurally identical or very similar with only small differences in mineral, void size and proportional content which could be easily identified from the recorded description notes and images. Therefore, all interpretation of the data are qualitative, based purely on the original microstructural observations.

4.3.5.2 Compositional Data

All elemental data was extracted from the Oxford Instruments INCA software (as mentioned above normalised compound wt%) and pasted into a Microsoft excel spreadsheet. A separate tab was used for the results of each material type to render the data more manageable. Therefore, all bulk results for the exterior coarse layer, the crucible main body fabric, internal glassy slag and lid as well as spot analyses of metallic prills were placed in different excel spreadsheet tabs. This raw data was saved and a copy was made to work on. Every bulk analysis was checked against original spectras to make sure the given values were accurate or at least that a given element was indeed present if a value for it was given. All negative numbers were zeroed and an average composition for each material layer in individual samples was calculated (from all spectra taken) using a simple formulae in excel. This average was then copied and pasted into another excel spreadsheet and organised into separate tables for the different material layers. These tables are presented in chapter 8.2.

The values for each element could then be plotted against one another to find any patterns or trends in the data which may point to differences in manufacture or use at intra-site or inter-site level. In addition, comparisons between the three main crucible types (C1, C2 and C3 discussed in chapter 6.2.6) were investigated. The results from this study were then compared to given compositional data from other crucible steel remains found in Central and South Asia. Only a few sources provided quantitative data enabling accurate comparisons to be made of the main body fabrics and internal glassy slag layers.

The plots were all made with standard Excel scatter graphs, giving the ratio between two element compositions for each sample. Care was taken to make the graphs identical in size as well as use the same colours and symbols for the same datasets represented in different graphs (e.g. same symbol for all C1 data). This should make the data easier to interpret and allow different graphs to be more easily compared to one another. Ultimately, not all graphs could be used in text as this would clutter and break up the flow, therefore only the most interesting or those which supported the in text discussion are provided.

4.4 Summary

The study comprises three main data-sets. The first is the location and site data collected during the Pioneering Metallurgy Project reconnaissance survey in 2010. The second is the archaeometallurgical material collected during the survey, and the third is the scientific analysis of some of these materials.

The survey consisted of daily excursions to known sites, recording important archaeometallurgical, historical and geological features. The primary focus was on direct evidence of past iron and steel production such as smelting and crucible waste deposits. Features were recorded as ‘locations’ and recording procedure involved taking GPS coordinates, photographs, and in-depth note taking on landscape setting, features present, technological material present as well as size of features and their state of preservation. This data was then digitised post-survey into a Microsoft Access database and locations were categorised into four main groups, historic, geological, ethnographic and metallurgical. Based on shared properties, similarity of deposit, material and distance, the 224 locations recorded were amalgamated to form 139 ‘sites’. The focus of this study lies with the metallurgical sites surveyed. Based on the dominant technological waste present on these sites, they were grouped into four main site types, smelting, crucible, smelting/crucible and crucible/smelting. The properties of each metallurgical site type was then assessed by size of deposit, deposit depth, preservation status and setting.

Technological waste was collected from the majority of metallurgical sites during the survey. This material, which consists of smelting slags, smithing slags, tuyeres, furnace wall, crucibles, coloured glassy slags, ores, geological fragments and metallic iron, forms the focal point of this study. All material was collected from the ground surface, making sure a good proportion of the material was taken. The assemblage is qualitatively representative of the material observed but not quantitatively representative. A visual macro-morphological analysis of the entire assemblage was conducted, whereby aspects such as size, colour, texture, shape, weight, magnetism and special features were recorded. This enabled the material to be grouped into several sub-types based on shared morphological attributes. All material sub-type weights by site were tabulated into an excel spreadsheet, enabling the assemblage to be quantified by overall material weight and proportion of sites on which they occurred. Material occurrence on sites was then assessed manually with the aid of the excel database, the detailed material and site descriptions as well as the photographic record, to identify specific metallurgical technologies. Spatial distribution of the identified technologies was assessed by mapping the sites on Google Maps and trends were investigated by comparing site properties such as setting and size.

The next step was the micro-structural and elemental analysis of 26 mounted crucible polished sections. Without permission to take the specimens out of the country, all material was analysed in IISc, Bangalore. Metallic prill microstructures were identified by optical microscopy while crucible fabrics were analysed by SEM-EDS. The data was then compared by crucible type at a regional level and to other crucibles found in Central and South Asia.

5 Characterisation of Surveyed Sites

Very few studies have tackled the identification and characterisation of archaeometallurgical sites in the Telangana region and none to date have recorded and analysed sites in detail. Only two authors, Thelma Lowe (1995) and Jaikishan (2009), have contributed to our knowledge of ancient iron and steel production in Telangana (chapter 2.3). However, Lowe's work has not been fully published and Jaikishan's research only provided a catalogue of archaeometallurgical sites with limited information on individual sites and technological waste present. Nevertheless, they were effective in disseminating the importance and demonstrating the sheer scale of northern Telangana's technological past, helping to highlight gaps in our understanding and forming the framework on which further research could be built. It is in this context that the Pioneering Metallurgy Project came into being (chapters 2.3 and 4.1) with an overall objective of investigating further the past metallurgical activities of the region (Juleff *et al* 2011).

The data obtained by the project forms the basis of this chapter which will deal exclusively with the characterisation of the archaeological sites identified and recorded. See chapter 4.1 for the methods used to collect, store and process the data. The primary aim here, is to provide a quantification of sites, formulate site types and compare site traits. The chapter will be divided into two main parts. First, the general site characteristics and quantification will be broadly defined. Then, trends between allocated site types (e.g. smelting or crucible sites), other site traits (e.g. setting or preservation) and environmental considerations (e.g. landscape or geology) will be assessed.

5.1 Site Characterisation

The characterisation of the archaeological sites forms the backbone of this study as it provides context for the material analysis in the following chapters. This is particularly crucial as no study to date (in Telangana) has supported technological material analyses with an in depth assessment of the archaeological setting. More information on how the data was collected during the Pioneering Metallurgy Project is provided in chapter 4.1.1. In summary, site data was collected through a system of diary keeping from all people involved in the project, whereby information recorded included the landscape setting, physical/geographical location (position within landscape as well as GPS coordinates), technological material present, features present, approximate size of features, state of preservation and what kind of material was sampled. All features or series of features were recorded as locations. In total, 224 different locations were recorded during the six weeks of fieldwork in 2010. These were amalgamated post-survey into 139 'sites' as outlined in chapter 4.1.3. Although location records were kept intact (appendix A) to preserve the high resolution details of each location, for ease of understanding, the data presented here will concentrate on the characterisation of the final sites defined from the analysis of the location records.

The sites were grouped broadly into historic, geological, metallurgical and ethnographic categories. The number of sites in each site group is displayed in figure 5.1. It is important to recognise a major bias towards metallurgical sites. As these were the main focus of the fieldwork, the balance between metallurgical sites and other sites presented here is not a reflection of reality. The generalised site groups incorporate different site types which were attributed to each depending on the features and archaeological material present. Historic sites were those of historic interest including ancient settlements, forts and temples but not necessarily related to the metallurgical technologies forming the focus of this study. Geological sites incorporated sites with potential technological-metallurgical connections such as modern quarries, mining pits and ore deposits. Metallurgical sites form the majority of the sites surveyed (Figure 5.1) and primarily consist of smelting and crucible steel sites. Ethnographic sites include operational or recently disused smithies (blacksmith workshops). In addition, two findspot sites were identified (Figure 5.1) which are locations where only a single or few artefacts were found. Both these sites are in agricultural fields and the material collected were surface finds. Since these have no significant amount of archaeological material, they cannot be attributed as sites proper and hence will not be discussed further.

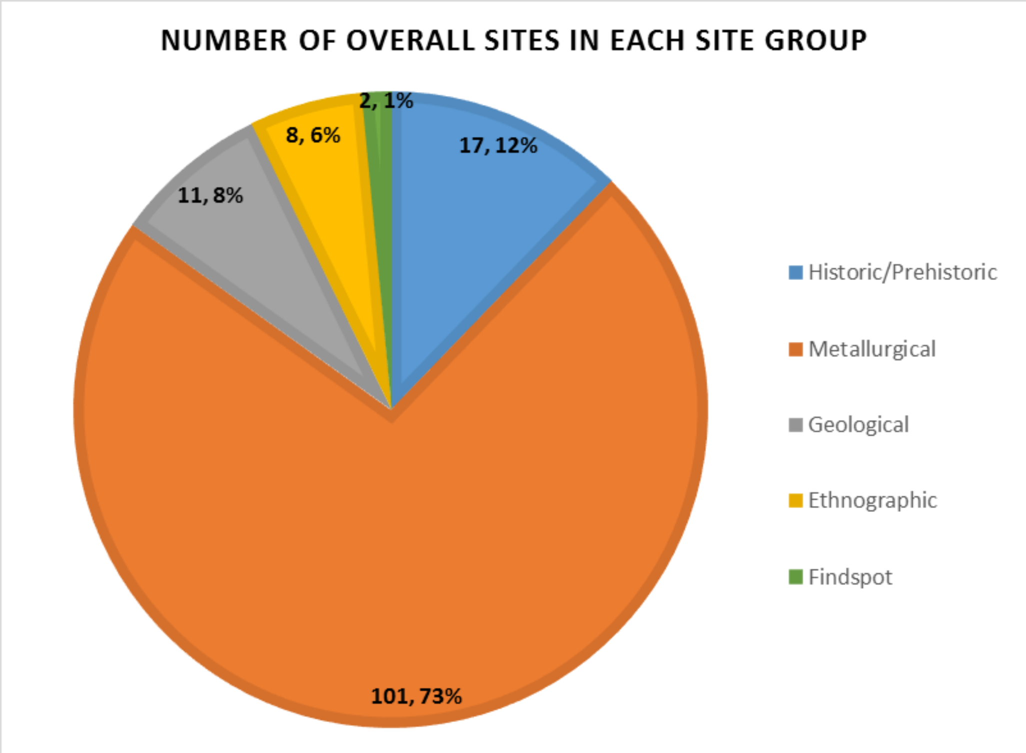


Figure 5.1 – Number of overall sites falling under the main site groupings.

The main aim of this section is to provide a sturdy archaeological background to support the more in depth analyses of the technological material in subsequent chapters. Each site grouping adds to our understanding of metallurgical production in the area. Historic sites provide temporal scale and help place past metallurgical activities within a historical context/landscape. Geological sites provide information of raw material distribution and procurement. Metallurgical sites themselves give an idea of the scale, nature and enable identification of methods of production. Ethnographic sites may also inform what final products were produced, how and where they were made, and by whom. Information may be gained on the identity of the people involved in the varying processes of manufacture and trade.

The following sections will introduce and discuss the major characteristics of each site type in all site groups. Only brief descriptions of the historic, geological and ethnographic sites will be given as they are not the main focus of this study, while greater discussion and interpretation will be attributed to the metallurgical sites. Refer to appendix A for descriptions of individual sites and to site numbers (in bold) in this chapter.

5.1.1 Historic Sites

Seventeen historic sites were recorded during fieldwork, accounting for 12% of the total (Figure 5.1). Although it cannot be ascertained whether they were associated with the metallurgical sites that form the main interest of this study, they do attest to the longevity of human activity and past landscape use in the region. The sites recorded were divided into several site types. The majority (over half) were ancient settlements and temples, while the others were either individual structures, forts, pottery scatters or prehistoric sites (Figure 5.2).

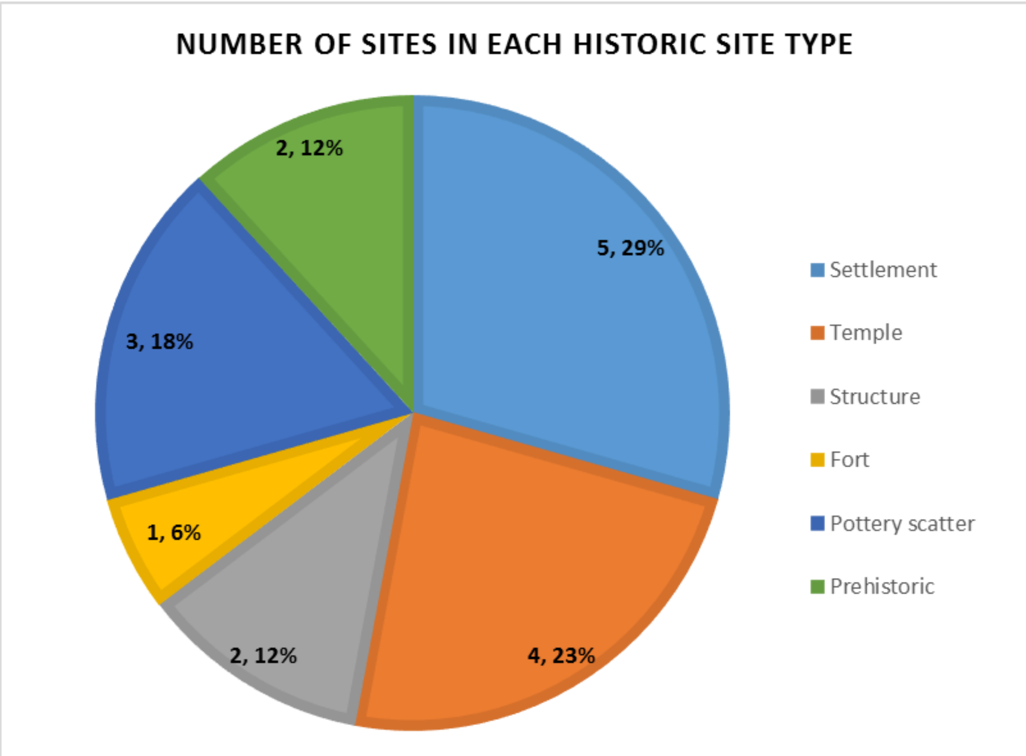


Figure 5.2 – Number and percentage of sites in each site type within the historic site group.

5.1.1.1 Settlement Sites

Five settlement sites were recorded. Most of these appear to be village ruins, but exact dates of habitation are not known. Sites **PM20**, **PM32** and **PM89** fall under this category. At **PM20** large foundation stones remain on the edges of agricultural fields while smaller cut or decorated stone elements are the only evidence that remains at **PM32** and **PM89** within fields or on the bare scrubland bordering agricultural land. These sites also typically have surface scatters of pottery attesting to their use and habitation in the past. For the most part, these sites remain undated but the stylistic stone decorations at **PM89** probably dates it to the 6-7th century AD (Jaikishan pers. comm., 2010). **PM78** is a more recent village abandoned in 1995 due to a flooding episode (Jaikishan pers. comm., 2010). Undergrowth has taken over the majority of the site but house walls still stand to roof height with some of the compounds repurposed for cotton plantations.

Arguably the most interesting and historically important site is **PM1**. This is the location of the well recorded walled town of Satavahana Period (2-3rd century AD), Kotilingala. The settlement was excavated by the State Archaeology Department from 1979-83 (Murthy 2006) and is discussed in more detail in chapter 3.3.2. The physical surface remains consist of a large sub-rectangular mound with partially surviving ramparts and outer ditch (Figure 5.3). The rampart survives in some areas up to c.3m in height while three tiered fields are present on the outskirts, suggestive of a stepped outer rampart. The remains are disturbed by the modern village and temple which occupy the eastern part of the mound, as well as the agricultural fields within and outside the surviving ramparts (Figure 5.3).

Figure 5.3 – Ancient Satavahana settlement Kotilingala (PM1). Edge of earthen ramparts with fields within (top left), part of settlement mound (top right), modern village occupying eastern part of mound (bottom left) and temple on north-east corner of ramparts overlooking the Godavari River (bottom right).

5.1.1.2 Temple Sites

In addition to settlements, four abandoned early temple sites were recorded. These undoubtedly vary in age and in the deities being worshiped. **PM2** is the temple associated with the modern village of Kotilingala (mentioned above). It lies on the north-east corner of the ancient settlement overlooking the Godavari River (Figure 5.3). It is dedicated to Koteshivava and there is evidence of brick constructions below the temple which may be part of the older rampart walls. Site **PM25** is found in close proximity to the smelting residue constituting site **PM24**. It is a small rectangular temple (c. 3x2m) with all four walls still standing and a roof constructed with stone lintels. The walls consist of horizontally laid stone slabs on the longest sides and vertically aligned slabs on the shorter sides. A carving on the exterior suggests that this temple was dedicated to Hanuman. The temple is believed to date from the 7-8th century AD (Jaikishan pers. comm., 2010). **PM138** consists of a small temple with a Nauda statue built on the north bank of a water tank (bund) which supplies the village of Polasa, Karimnagar district.

Perhaps of greater interest to this study, is the more recent temple recorded in the village of Ibrahimpatnam. Site **PM109** is a small rectangular concrete building not more than 5x3m in size with whitewashed exterior walls (Figure 5.4). It is dedicated to both Mammaya and Vishwakarma idols which are found in the shrine (Figure 5.4). Mammaya is a deity of iron and steel (Jaikishan 2009; 2015) and the fact that this temple is still active, highlights the importance of this industry in the recent past to the inhabitants. Indeed, small crucible fragments were found surrounding the small temple complex suggestive of past steel production in the vicinity. This is supported by the smelting and crucible waste material constituting sites **PM106** and **PM108** also within the same village.

Figure 5.4 – Temple (PM109) recorded in the village of Ibrahimpatnam (left) where Mammaya and Vishwakarma idols were worshiped (right).

5.1.1.3 Structures

Two individual structures of interest were recorded. **PM86** is a c.3m high mound with an abundance of white sandstone fragments indicating a collapsed structure. It is reputedly an early Buddhist structure dating to the 1-5th century AD (Jaikishan pers. comm., 2010) and was recorded due to its proximity to site **PM85**, which is a large surface scatter of smelting debris. Unfortunately, there was no surface evidence for any correlation between this Buddhist structure and the technological activities occurring nearby.

Perhaps of more interest however, is 'the trader's house' centrally located within the village of Konasamudram (site **PM66**) and believed to be at least 200 years old (Jaikishan pers. comm., 2010). It is a two storey timber and mud-brick structure with a central courtyard (Figure 5.5). The house is c.4-5m high with a clay-tiled roof. The south-east corner is severely damaged where the walls have partially collapsed (Figure 5.5). The wood around the doorways are highly ornate with carvings and some of the courtyard walls have niches (Figure 5.5) reputedly for storage of goods and money. This distinctive structure is of particular interest due to the fact that Konasamudram was identified as a major crucible steel production centre by the European traveller Voysey, in the early 19th century AD

(Voysey 1832). Indeed, Voysey described the export of the steel ingots to Persia (see chapter 1.2) and it is not inconceivable that this house was owned by the merchants.

Figure 5.5 – 'The trader's house' (PM66) in the village of Konasamudram. Note the central courtyard and partially collapsed wing (top right), the niches in some of the walls (bottom left) and the ornate woodwork around the doorways and windows (bottom right).

5.1.1.4 Forts

The remains of a fort of uncertain date were recorded at **PM37**, close to Lachakkapet, Karimanagar district. The site consists of standing walls surviving up to 5m in height (Figure

5.6). The walls are 1 to 1.5m thick, constructed with 10-13 mud-courses, c.55cm long and c.40cm high. They form an enclosure c.90m in length, east to west, and c.55m in width (Figure 5.6). The south end of the site has no visible wall structure remaining but the enclosed area is used for cultivation (Figure 5.6). Repairs appear to have been made in some parts and fragments of tap slag and pottery are visibly embedded in the brick fabric of the walls. It can be assumed that the slag and pottery predate or are contemporary with the wall construction. Slag scatters were observed on the ground and the abundance of slag in the walls suggests the presence of smelting within the fort area.


Figure 5.6 – Walls of the ancient fort close to the village of Lachakkapet (PM37). Note the extent of the enclosed fort area now used for agriculture (left) and the wall construction with large mud-courses (right).

5.1.1.5 Pottery Scatters

In addition to settlements, temples and structures there were several sites recorded that had an abundance of surface finds, suggestive of past human activity. Sites **PM4**, **PM41** and **PM53** are concentrations of pottery finds, mostly in agricultural fields and field banks, close to sites where technological debris was observed and recorded. Unfortunately, the pottery cannot be accurately dated as there is no existing archaeological typology of local pottery wares, but their presence indicates potential past habitation in the vicinity of iron and steel production sites.

5.1.1.6 Prehistoric

Two prehistoric sites were recorded. **PM81**, c.1km north-east of Katkapur, Karimanagar district is a surface scatter of mixed material within a ploughed field, including microlithic flaked quartz/chert tools and cores as well as pottery and occasional slag. On the other hand, **PM105**, c.500m north-east of Dacharam, Karimnagar district was the location of several megalithic burials, probably of Iron Age date. Since these are not directly relevant to the study they will not be discussed any further here.

It is important to mention that although a few historic sites were recorded during the fieldwork, it was not its primary aim and hence does not fully represent the historical remains present in the area of study. The purpose was to record some sites of potential significance close to metallurgical sites to highlight the longevity of human metallurgical activity in the area and contextualise the metallurgical sites in terms of settlement types and patterns. In addition, since excavation was not permitted and all finds were collected from the surface, the historical vestiges were often the only temporal indicators for these activities. It may also be important to mention here that many of the villages themselves were historic, with many having buildings of indeterminate age and in various states of preservation.

The older buildings, which could possibly be several centuries old, were generally recognisable by their construction methods and choice of materials. It was common for older buildings to be built with unusually shaped clay bricks or constructed of mud-courses (Figure 5.7). The clay bricks were generally square or rectangular in plan (mostly <30cm in length) but were quite thin (mostly <7cm in height). These differed from the more modern material choices consisting of either regular rectangular bricks or concrete. Some sites also appeared to be elevated from the surrounding landscape, built on raised mounds indicating long occupation deposits (tel sites). The remains of large man-made water reservoirs (bunds) adjacent to many villages also attests to the intensive use of this landscape. Further work would be required to record all historic features and provide a complete temporal scale for human activity, habitation and land use in the region. Refer to chapter 3 for more information on settlement, land use, landscape and infrastructural setting of the region.

Figure 5.7 – Houses constructed of mud-courses suggesting that they must be of a considerable age.

5.1.2 Geological Sites

Eleven geological sites were recorded, accounting for 8% of the total (Figure 5.1). These were characterised into three major site types covering ore deposits, mining pits and quarries. Ore deposits and quarries make up the majority of the geological sites surveyed, accounting for 46% and 36% respectively, followed by potential mining pits making up 18% (Figure 5.8). The importance of recording these sites and discussing them here lies in their possible connection with past technological activities. The manufacture of iron and steel cannot happen without the procurement of the raw materials necessary to produce them. Therefore, the identification of sources of iron ore and their extraction is of great importance. However, in saying that, it is important to mention that not all potential ore sources were investigated and those recorded are by no means representative of the full extent of ore availability in the region. What these few records do and were aimed to achieve, is to give an indication of the potential sources of ore and some of the means by which people may have extracted or obtained this resource for iron and steel production.

This section will briefly describe the general characteristics of the sites in each geological site type.

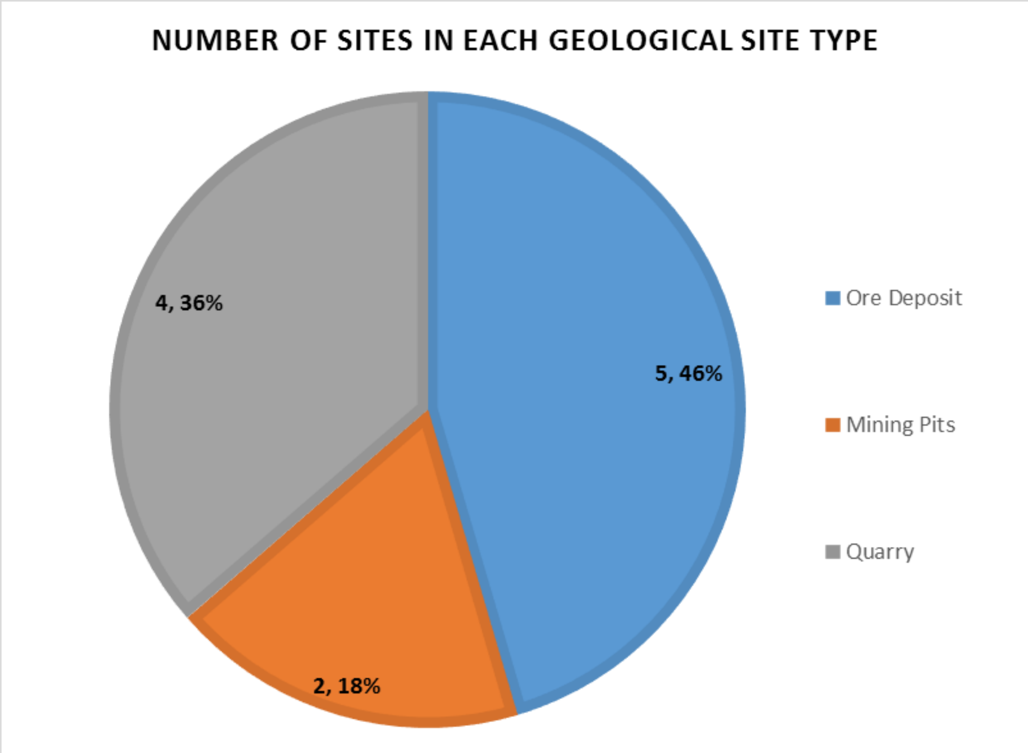


Figure 5.8 - Number and percentage of sites in each site type within the geological site group.

5.1.2.1 Ore Deposits

Five ore deposits were recorded in proximity to metallurgical sites that could potentially have been sources of iron ore. The majority of these are hillocks of varying sizes with iron ore deposits either scattered on the ground surface or within larger rocky outcrops (see chapter 3.1 for more information on local ore formations). The largest investigated was **PM6** which is the site of the large hill, Sirikonda Gutta in Karimnagar district (Figure 5.9). Abutting the base on the southern side is a village of the same name with evidence of past ironworking. The hillock is scattered with visible banded magnetite outcrops, while three modern quarry scoops at its base (between the hill and village) show that the upper 30cm horizon is reddish-brown and contains abundant magnetite cobbles (Figure 5.9). The extensive survey of the hillock did not reveal any surface pits or scars typical of ore extraction but ore could have been picked from the surface. The other sites (**PM36**, **PM114**, **PM122** and **PM136**) on the other hand, are smaller, low hillocks typically <150m in circumference. Most of these are also in vicinity to villages with recorded metallurgical activity. All have surface scatters of ore (Figure 5.9) or larger exposed banded magnetite deposits making them prime suspects for procurement. None showed signs of past mining/extraction but the evidence may have been lost to time or hidden by the shrubby vegetation which predominates.

PM6

PM6

PM36

Figure 5.9 – Large hillock Sirikonda Gutta - PM6 (top left), the modern quarry scoop at its base (top right) and some of the banded magnetite fragments visible on the ground surface of PM36 (bottom left).

5.1.2.2 Mining Pits

Two probable mining pit sites where iron ore could have been extracted in the past were recorded. The most probable sources of iron ore, as is suggested above, appear to have been the rocky hillocks scattered throughout the landscape (see also chapter 3). Therefore, it is not surprising that all potential evidence for extraction was identified on such hills.

The two most likely sites recorded where ancient ore procurement could have taken place are **PM17** and **PM29**. Banded magnetite ores of varying grades were seen and collected from both sites. **PM17** consists of small quarrying pits on the north-east side of a hill close to the village of Shekalla, Karimnagar district. These small depressions, less than 3m wide, are almost entirely filled with banded magnetite fragments and are probably for ore extraction (Figure 5.10). Downslope of each pit, are spoil heaps, presumably material removed from the pits. These are elongated and arced following the outline of the circular depressions. **PM29** is located on a small hill, recently terraced for mango cultivation close to Mallapur village, Karimnagar district. It appears to be a source of banded magnetite, with loose fragments scattered over the surface. One area, at the top of the hill remains relatively undisturbed. Here, there are traces of 3-4 small partially filled in pits (Figure 5.10). The dense shrub cover prevented in-depth recording but they may be evidence for past mining or quarrying of ore. The pits at both sites are quite small, being a few meters in diameter. Both sites are also in close proximity to recorded ancient iron production sites; **PM14** in the village of Shekalla is close to **PM17**, and **PM28** close to Mallapur village is c.250 meters north-west of **PM29**. The date of these features cannot be asserted at this stage but the fact that mining activity appears to have taken place on some of these hillocks in the past adds credence to the possibility that they were primary sources of iron ore.

PM17

PM29

PM29

Figure 5.10 – Probable mining pits at PM17 close to Shekalla (top left) and PM29 close to Mallapur (bottom and right).

5.1.2.3 Quarry Sites

Four quarry sites were recorded. These were found at the bases of small hills where material was scooped out, leaving circular (or semi-circular) quarry scars in the ground mostly <30m in width (Figure 5.11). Neither their function nor date are known but the fact that in most cases they are not entirely covered by shrubby vegetation (as was seen with potential mining pits above) suggests that they may be relatively modern, perhaps sources of material for road making and general construction.

Further investigation of the excavated sections reveals that some may not have been ore extraction sites. For example, at **PM121** situated close to Gutrajupalle, Karimnagar district, the small hill showed signs of quarrying with evidence of spoil heaps but there was no iron ore to be seen at the site. It is possible therefore that some of these excavations had nothing to do with the past metallurgical activities recorded in their vicinity. In saying this it is also possible that other raw materials employed in the production of iron and steel such as clay or sand could have been extracted from these or other similar locations.

Iron ores were found at the other sites. At **PM12**, close to Kalleda, Karimnagar district, ore was collected from the surface and from the excavated section. Unfortunately the ore observed at the site appeared to have been of a low-grade, sandy/gritty type so it is uncertain whether or not it could have been used for smelting. It is of course possible that all useable ore has been extracted leaving only low-grade material. A similar situation was recorded at **PM5** (Buggaram) where the upper horizon of the sections was a red iron-stained lateritic soil overlaying a pale cream decayed quartz-rich bedrock (Figure 5.11). The quarry site at **PM17** on the other hand, was in banded-magnetite geology with an abundance of loose fragments found spread over the entire hillside along with large amounts of magnetic gravel.

PM12

PM13

PM5

PM5

Figure 5.11 – Quarry sites at PM12 close to Kalleda (top left), PM13 close to Yeshwantareopeta (top right) and PM5 close to Buggaram (bottom).

5.1.3 Ethnographic Sites

Eight ethnographic sites were recorded, accounting for 6% of the total site records (Figure 5.1). All of these are currently operational smithies, that is, workshops where blacksmiths ply their trade by working iron and steel objects and tools. Interviews with most of the blacksmiths were recorded but will not form the focus of this section. The ethnographic dimensions of iron and steel research in the Telangana region is the subject of another research project (Neogi, forthcoming). The transcripts and interpretive results of these interviews will be available in his study. This section will deal with the general descriptions of the operational smithies recorded.

5.1.3.1 Operational Smithies

In total, ten smithies were recorded at the 8 sites as some of the sites consisted of two adjoining forging areas. All of these workshops or working areas have distinct similarities. They are all at ground level and consist of a small hearth powered by bellows of various types. They include an anvil and a receptacle filled with water for quenching (Figure 5.12). Although each element may differ slightly in construction, the layout of these three main features is almost identical in all of the workshops recorded. The smith usually squats or sits on a small stool (usually a piece of brick, stone or wood) in the centre of the arrangement, with the hearth placed on the left, the anvil in front and the quenching pot or receptacle on the right (Figure 5.12). All these are within arm's length of the smith who can reach and operate all elements required for smithing. This arrangement means that all operations, including bellowing can be done by the smith himself without having to change position. The few exceptions where this was not the case, a family member was helping, for example, a child or wife operating the bellows.

The hearths usually consisted of a shallow ground depression with a small straight charcoal-retaining wall. This wall differed in construction, either consisting of stacked bricks (**PM16**, **PM23** and **PM107**), rocks (**PM15** and **PM71**) or made out of clay (**PM7** and **PM43**). All had a central hole at their base with a slight downwards angle towards the charcoal side to accommodate the air supply. The air supply was usually provided by crank bellows, except at **PM7** where one of the hearths was powered by mechanical bellows driven by an old bicycle wheel and drive belt (Figure 5.12). The anvils were almost identical, being small and square in section (c.10cm and showing different levels of mushrooming), less than 30cm in visible height and all embedded within a wooden block (beam or tree truck), itself being set into the ground, presumably for stability (Figure 5.12). Two main quenching receptacle types also appear to have been used. At **PM16**, **PM23** and **PM71**, clay (or metal) pots filled with water were employed, whereas at **PM7**, **PM43** and **PM107**, carved stone troughs embedded in the ground were preferred (Figure 5.12). In addition, the quenching trough at **PM7** appears to have also been used as a sharpening stone, with distinct linear marks engraved/carved on its edges.

With few exceptions, all smithies were permanent, outdoor installations, typically located in front of the smith's residence or within the smith's compound. The two exceptions are the smithies recorded at **PM23** and **PM107**. The smith interviewed at **PM23** was itinerant with a temporary installation that could be dismantled and transported to other locations. None of the tools he used were fixed; a few bricks formed the retaining wall to his hearth, the anvil was set into a free standing wooden plank not embedded in the ground and a clay vessel was used for quenching (Figure 5.12). Two smithies were recorded at **PM107**, in the village of Ibrahimpatnam, Karimnagar district. Both were consistent to others but one of them was located inside a building, while the external smithing area was covered by a corrugated iron roof. It appears that the smiths from this workshop had a higher social status within their community than the majority of other smiths interviewed.

Of special interest was site **PM139**, Dustarabad, Adilabad district. Although no smithies were recorded, this location marks the house of a smith whose family descended from smelters. Family members say that smelting production stopped in the 1920’s and the older members say that the last smelt occurred c.1950. The house is surrounded by smelting debris, most notably tap slag, large dense furnace bottoms and refractory materials suggesting that the houses may have been built on a former slag mounds. This site is the subject of in-depth study by Neogi (pers. comm., 2016).


PM7


PM16


PM23


PM43


PM71


PM107

Figure 5.12 – Ground level smithies recorded at PM7, Sirikonda (top left), PM16, Shekalla (top right), PM23, Narella (centre left), PM43, Rangapeta (centre right), PM71, Nagaram (bottom left) and PM107, Ibrahimpatnam (bottom right). Note the very uniform layout of the three main components, the hearth, anvil and quenching recipient.

5.1.4 Metallurgical Sites

The metallurgical sites described in this section are the main focus of this study. In all 101 metallurgical sites were recorded during the survey, accounting for 73% of the total site records (Figure 5.1). The sites have been characterised by the type of technological remains present (see chapter 4.1 for methods). This included crucible and smelting sites as well as those that had evidence for both. In those cases, the sites were characterised as crucible/smelting or smelting/crucible, the first category comprising the dominant technological waste material observed at those sites. Although some may have had evidence for other technologies (such as smithing), they were all characterised within the two main technologies, smelting or crucible sites, representing the manufacture of iron and steel respectively. More detailed descriptions and potential technological groupings will be assessed and discussed in chapters 6 and 7, where the archaeological waste material from each site will be analysed, characterised and presented.

It is apparent that by far the majority of the sites surveyed were smelting sites, accounting for 76% of the total (Figure 5.13). Smelting/crucible and crucible/smelting sites accounted for significantly less with 15% and 8% respectively (Figure 5.13). Sites with only crucible waste were rare and only one was recorded. Although only crucibles were found at this site, it is in the same village (in close proximity) to other sites which have mixed crucible and smelting waste. Therefore, it will be discussed within the crucible/smelting site type. This section will deal with the brief descriptions and general trends observed in each site type. Detailed description of individual sites are given in appendix A.3.

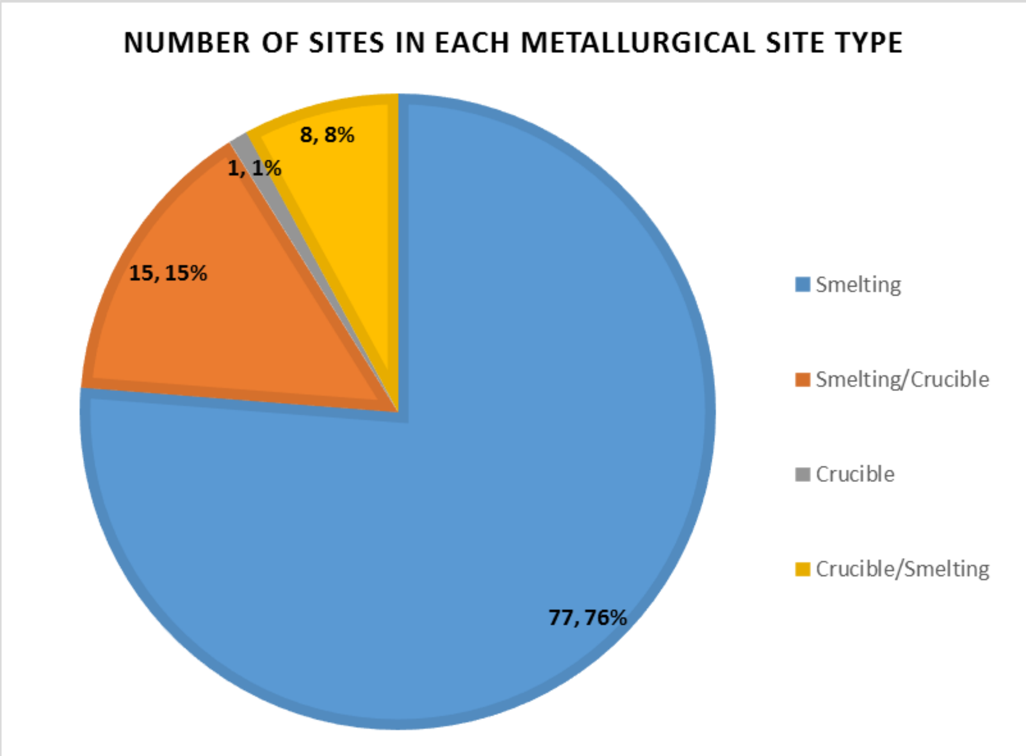


Figure 5.13 - Number and percentage of sites in each site type within the metallurgical site group.

5.1.4.1 Crucible and Crucible/Smelting Sites

Nine crucible and crucible/smelting sites were recorded. These all share similar characteristics in the fact that the majority of the archaeological remains are associated with crucible steel production, for the most part broken fragments of the crucibles themselves. All also have secondary material such as technical ceramics (furnace lining and tuyeres) and slags associated with iron smelting but in much less quantity. Thus, crucible steel dominates these sites.

Some of these sites appear to have been connected in some way as they were found close to one another, forming what could be described as larger village complexes. There are three of these larger agglomerations of locations and sites based around the villages of Konasamudram (Nizamabad District), Konapur (Karimnagar District) and Parasurampalli (Warangal District). These appear to have been larger (in their extant and abundance of material residue) than the majority of the other crucible sites. It is possible that they were more specialised centres of crucible steel production where activities were centralised around settlements.

Konasumudram is probably the most well-known crucible steel production centre in the region, from the early European account of Voysey (see chapter 2.2) and later archaeometallurgical work by Lowe and Jaikishan (see chapter 2.3). The complex encompasses three recorded metallurgical sites, **PM65**, **PM67** and **PM68** (Figure 5.14). **PM65** comprises two disturbed mounds of technological debris, approximately 20m apart on the north-eastern edge of the village (Figure 5.15). The large mound is c.30x16m, orientated north-south with a surviving height of c.4m, partially disturbed by modern buildings to the south and west. The second mound measures c.7-8m in diameter and c.1.5m in height, and appears to be more disturbed with less consolidated material, possibly suggesting it derives from field clearance. **PM67** lies c.200m south of **PM65** on the south-eastern edge of the village (Figure 5.14). It consists mostly of crucible remains scattered in a field c.28x18m in size with a more dense concentration to the north where the material forms part of a brick and drystone wall (Figure 5.15). **PM68** is located c.75m north-east of **PM67** within the village itself (Figure 5.14). It is a disturbed deposit of crucible fragments exposed in a pit dug for a new concrete pillar. A dense deposit of crucible fragments was visible below the surface at the time of the survey (Figure 5.15). These sites reveal that the eastern part of the village was where the most intensive production activities took place. The major surviving deposits are now only noticeable on the edges of the village itself but evidence at **PM68** suggests that at least part of the remains must be below the modern settlement. The 'trader's house' constituting **PM66** (discussed above) is also within this part of the village, and lies less than 100m from **PM67 and PM68** (Figure 5.14). This adds credence to the suggestion that past metallurgical activities were more intense in the eastern part of the village.

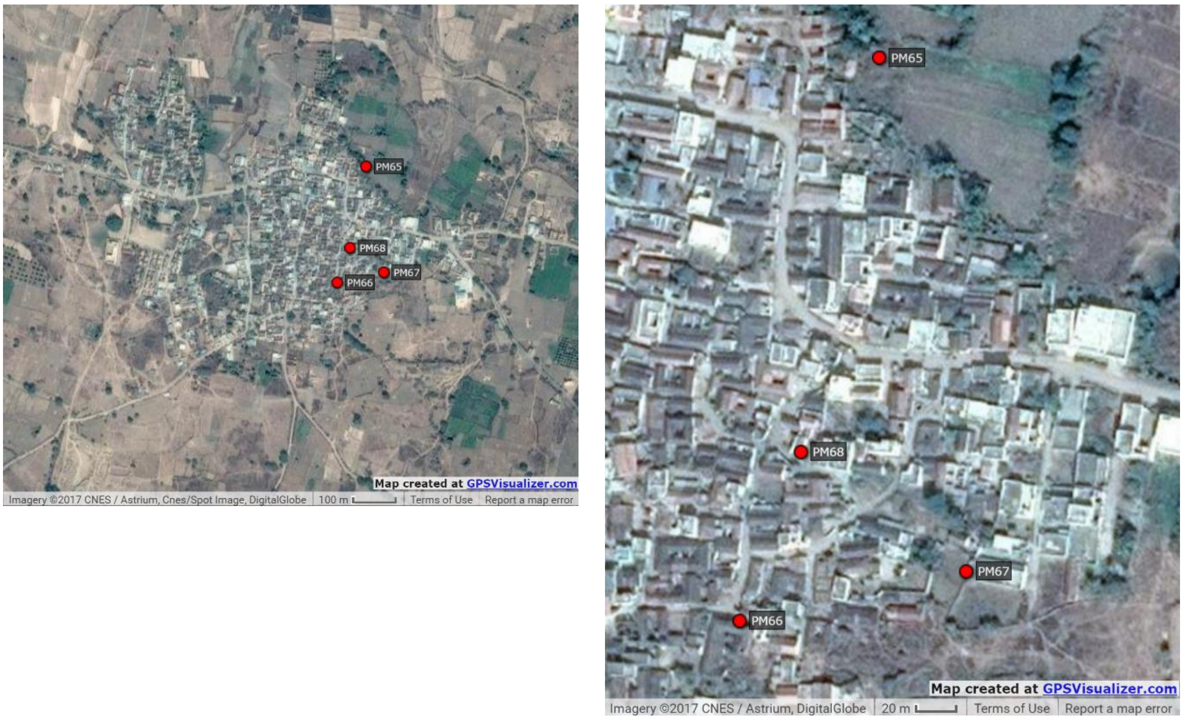


Figure 5.14 – Location of PM65, PM66, PM67 and PM68 within Konasumudram. Note the concentration of these sites in the eastern part of the village (left).

PM65

PM65

PM67

PM68

Figure 5.15 – Metallurgical waste mounds at PM65 (top images), the northern part of PM67 (bottom left) and the pit exposing dense layers of crucible waste at PM68 (bottom right).

Konapur is a very similar village approximately 10km east (as the crow flies) of Konasamudram. It encompasses two crucible/smelting sites, **PM60** and **PM62** but it is also important to mention that there is one smelting site (**PM61**) c.200m north of these, on the northern edge of the village which is likely to be associated. Smelting/crucible site **PM63** and smelting site **PM64** are also within 1km of the village (Figure 5.16).

Site **PM60** is situated in the north-western part of the village (Figure 5.16) and primarily comprises two large ovate mounds of material (Figure 5.17). The smaller of the two is on the very edge of the village, and measures c.20x12m and 3-4m in height, while the larger mound is 50m east, within the village, and measures c.40x30m and 5-6m in height. The debris comprises primarily of crucible waste with some evidence for smelting in the form of roppey tap slags and dense furnace slags. Both mounded deposits are disturbed by the settlement either with structures built on top or with roads bisecting part of the remains. It is likely that they extended further into the village as there are scatters of material surrounding the mounds but subsequent settlement expansion may have disturbed the evidence. This is supported by the large amount of residue found 100m south of the mounds, within the village. Here waste, including smelting slags and crucible fragments, was observed in substantial mud house walls and scattered along surrounding paths and roads (Figure 5.17). This suggests that the north-western part of the village was the centre of metallurgical activity in the past and the sheer quantity of the remains must mean that the activity was intensive.

The other site is **PM62**, located 400m west of the village in a field just to the north of the main road (Figure 5.16). It constitutes remnants of an old stone temple/shrine to Sri Anjaneya surrounded by an extensive disturbed spread of technological debris, covering an area c.100m^2 (Figure 5.17). Once again the material is primarily composed of crucible remains with some smelting slags and refractories.

Figure 5.16 - Location of PM60, PM61, PM62, PM63 and PM64 within or close to Konapur. Note the concentration of these sites in the north-western part of the village (right).

PM60

PM60

PM62

Figure 5.17 – Large mound of material at PM60 (top left), metallurgical debris within some of the mud wall structures in the same village (bottom left) and the shrine stones at PM62 surrounded by scatters of metallurgical waste (right).

Parasurampalli (**PM75**) was one of the most southerly sites surveyed. It is located in Warangal District approximately 100km south-east of the main research area. The village constitutes one of the largest metallurgical complexes recorded. It includes huge quantities of smelting dominant remains at site **PM74** but there are also three large deposits of crucible remains at **PM75** (Figure 5.18) which will be described here. **PM75** is approximately 250-300m south-east of the village within agricultural fields (Figure 5.18). It comprises three mounds of predominantly crucible fragments forming an arc within an 80m radius (Figure 5.19). The southernmost deposit has recently been flattened to make room for cotton plantations but the imprint of the former heap remains indicating an original size of c.30x50m (Figure 5.19). The other two mounds of material are better preserved, incorporated within field boundaries. The central mound is the largest at c.30x45m in size and c.1.5-2m in height, while the easternmost heap is c.25x10m and 1.5m in height (Figure 5.19). The material found at **PM75** is primarily crucible fragments but there is evidence of smelting slags and refractories. The site as a whole forms a large complex c.350-400m across, where smelting activities dominated the northern and western parts, and crucible steel manufacture the south-eastern section.

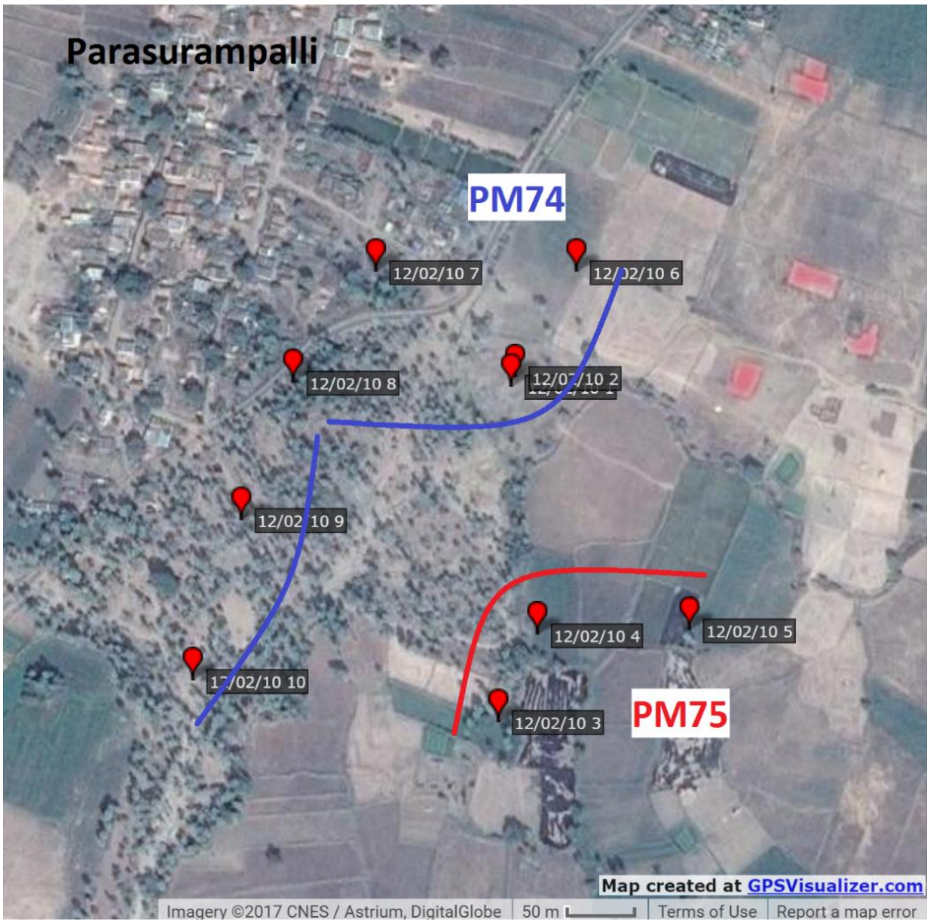


Figure 5.18 – Individual locations marking mounded deposits or thick scatters at PM74 and PM75, Parasurampalli. Note the three deposits constituting PM75.

Figure 5.19 – Metallurgical waste at PM75, the disturbed southernmost deposit (top left), the central heap (top right and bottom left) and the easterly most heap (bottom right).

Another important site is **PM103** (Gopalpur, Karimnagar District) which may also be part of a larger complex as there are again several sites within the same village. The associated sites are **PM101** (southern edge of village) and **PM102** (central within village) which also have concentrations of metallurgical debris but due to the predominance of smelting waste, they were individually characterised in the smelting/crucible group (Figure 5.20). The crucible waste that predominates at site **PM103** suggests that the main crucible steel production area was on the western edge of the village. The site consists of a collapsed drystone tower/fort with secondary mud capping containing significant quantities of crucible fragments and the remains of a small crucible waste heap (with some smelting slag) adjoining it (Figure 5.21). The tower itself stands on a rocky outcrop overlooking the main part of the village.

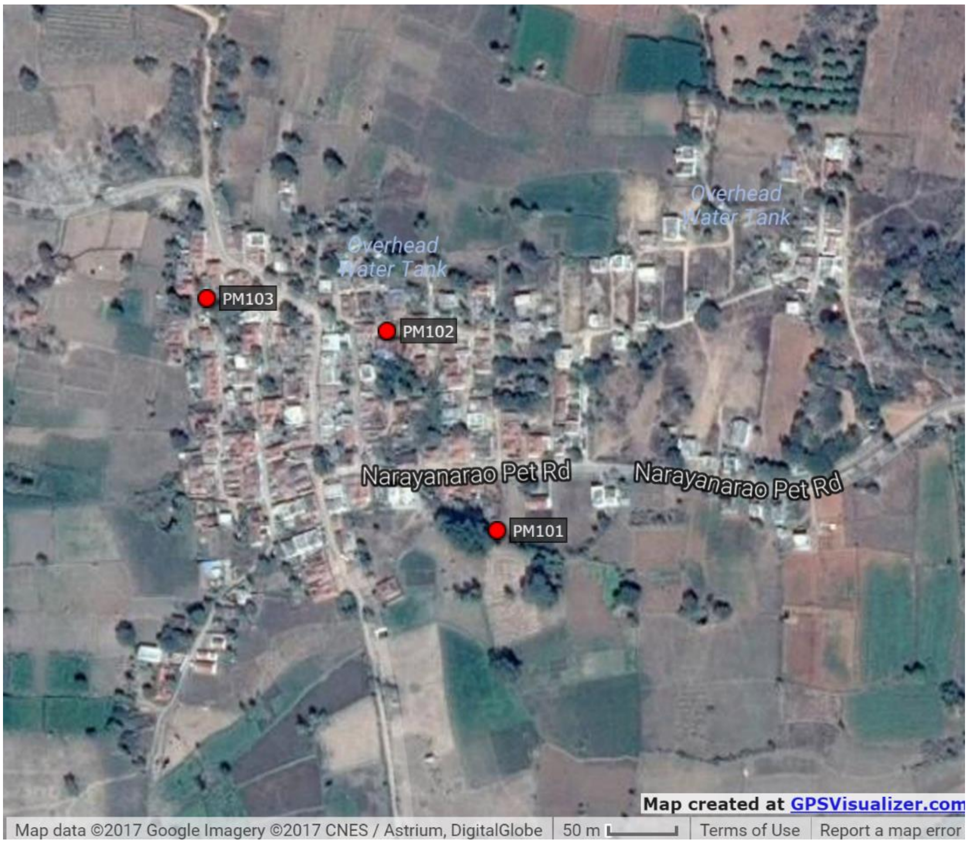


Figure 5.20 – Location of PM101, PM102 and PM103 within Gopalpur village.

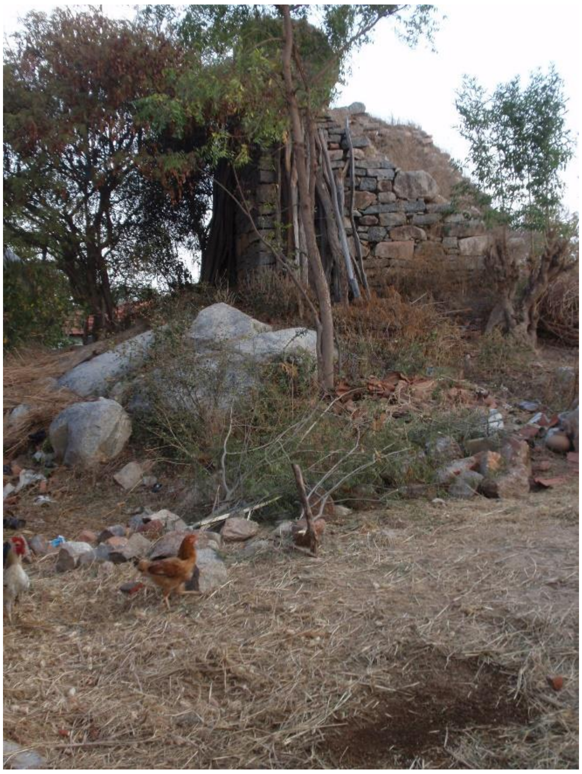



Figure 5.21 – Ruinous tower at PM103 (left) and part of the waste heap next to it (right).

The remaining two crucible/smelting sites are **PM106** and **PM119**. These are for the most part much smaller than the large complexes discussed above, often comprising just one heap of metallurgical waste. **PM106** was found centrally located within Ibrahimpatnam village, Karimnagar district. It consists of a large enclosed area associated with a modern water tower which appears to have been built on top of a metallurgical waste heap (Figure 5.22). The material was thinly scattered across an area c.50x30m. There was an increased concentration of debris at the eastern end of the scatter, heaped near an enclosure which formed a boundary of an open expanse of land. The heap was c.1m in height and 5-10m in width, showing a larger proportion of crucible waste than smelting remains (Figure 5.22). It is also important to mention that on the north-eastern edge of the same village there is a smelting site (**PM108**). It is not known whether these were contemporary but they could be associated.

PM119 is located on the north-western edge of Gutrajupalle village, Karimnagar district and consists of a mostly levelled metallurgical waste heap just north of the main road. The partial remains of a heap were visible in a natural dip in the ground surface on the southern part of the scatter. The northern extent of the scatter seemed to be predominantly smelting waste (slags and refractories) but the southern part (closest to road) had a large proportion of crucible waste. A ditch next to the road (following its length) seemed to cut through the heap. Due to the high level of disturbance, the extant of the remains was difficult to determine but it is noteworthy that a larger smelting site (**PM120**) was also recorded on the eastern edge of the village which may be associated.

Figure 5.22 – Modern water tower at PM106 (left) and the heaped material waste on the eastern end of the enclosure (right).

5.1.4.2 Smelting/Crucible Sites

Fifteen smelting/crucible sites were recorded. All these sites share characteristics in the fact that they are all associated with crucible steel production (like the sites discussed above) but they differ by having an apparent predominance of iron smelting waste. These smelting remains are mostly slags (tap and furnace) mixed with refractory material such as furnace lining and tuyeres (see chapter 6). Hence, the crucible remains present at these sites appear to be secondary, in all cases being less prominent than smelting waste.

The majority of these smelting/crucible sites are very disturbed, comprising dense scatters of metallurgical debris with few of the deposits remaining intact. Perhaps the best preserved site is **PM55** (c.900m north of Nawabpet village, Adilabad district) which has a large oval mound c.55m in length and c.20m in width, with a height of c.2-2.5m. The site is surrounded by agricultural fields with some evidence of technological debris scatters which may have come from the larger mounded deposit. The mound is well preserved but is adjacent to a road and several smaller, low, unconsolidated sub-circular mounds (<10x10m) were recorded on the other side of the road, probably representing road clearance material derived from the main deposit. The nature and positioning of the metallurgical waste is interesting. The south-western half of the large mound is dominated by crucible debris, while the north-eastern half appears to be composed of smelting waste, suggesting that iron smelting and crucible steel production occurred simultaneously but operated at opposite ends of the site.

The next best preserved site is **PM18**. It is located on the southern edge of China Nakkalapet village (Karimnagar district) within the field systems on the right hand side of the main road leading from Madradamanapeta to the village. It primarily consists of a single large mound of debris, approximately 50m in length and 15m wide (Figure 5.23). The height of the mound varies from c.0.5-1.5m. Although it is one of the better preserved smelting/crucible sites recorded, it appears to have been heavily disturbed by the surrounding cultivation, with large amounts of material removed that expose sections in the mound (Figure 5.23). There is also a significant amount of scattered material within the fields surrounding the waste heap which probably derives from this larger deposit (Figure 5.23). The material observed is primarily smelting remains such as tap and furnace slags as well as refractory material such as furnace lining and tuyeres. Crucible fragments were also recorded and appear to be more abundant in the northern part of the mound, while the better preserved southern end shows little evidence of crucibles. Once again this suggests that iron smelting and crucible steel production occurred concurrently and that the technologies were segregated on site, with one area dedicated to iron and another to steel production. It is also important to mention that another site (**PM19**) was recorded c.100m south-east, consisting of more scattered material of similar type to **PM18**. It is possible that this dense scatter, although now very disturbed, could have been the location of a former waste mound.

Figure 5.23 – Large debris mound at PM18 (top left/right and bottom left), notice the disturbed exposed sections in the mound (top right) and the dense scatters of material in the fields surrounding the heap (bottom right).

Four smaller smelting/crucible sites were also found within or on the edges of villages. All of the remains found at these sites were disturbed, primarily by later settlement activities. **PM9** is interesting as it consists of a small mound of metallurgical residue, c.7x6m in size, within a house compound centrally located within Sirikonda village, Karimnagar district

(Figure 5.24). The mound itself appeared to be mostly composed of iron smelting residue but some of the surrounding mud walls contained metallurgical waste including crucible fragments (Figure 5.24). The village had other evidence for past metallurgical activity. The most notable is smelting site **PM8** to the north-west of **PM9**.

PM102 is another similar site located centrally within Gopalpur village, Karimnagar district but appears to be bigger in scale. It encompasses several locations where material waste was observed. As previously mentioned, this site (a series of locations) is associated with crucible/smelting site **PM103** on the western edge of the village and smelting/crucible site **PM101** on the southern edge of village (see Figure 5.20). The material observed at **PM102** comprises primarily of smelting remains but there are some crucible fragments present. This differs from **PM103** where crucible remains predominate. The majority of the metallurgical debris at **PM102** appears to be concentrated in a large, sparse and disturbed scatter, c.30x30m, in a derelict, open shrubby area surrounded by houses (Figure 5.24). The rest of the evidence is primarily found within the mud walls of houses and compounds where smelting and crucible waste appears to be abundant (Figure 5.24). **PM101** is situated in a backyard on the southern edge of the village. It consists of material scatter which may have been used as road ballast. **PM101**, **PM102** and **PM103** are probably part of a larger metallurgical enterprise focused in and around the village, where the majority of the smelting took place on the southern end and central parts of the village with crucible steel activities concentrated on the western side.

The other site is **PM133** where fragments of metallurgical waste were observed at the base of a small fort situated c.310m south-west of Fakirkondapur village, Karimnagar district. It surrounds a hilltop of a rocky outcrop and the metallurgical residue is likely to have come from the crumbling mud walls.

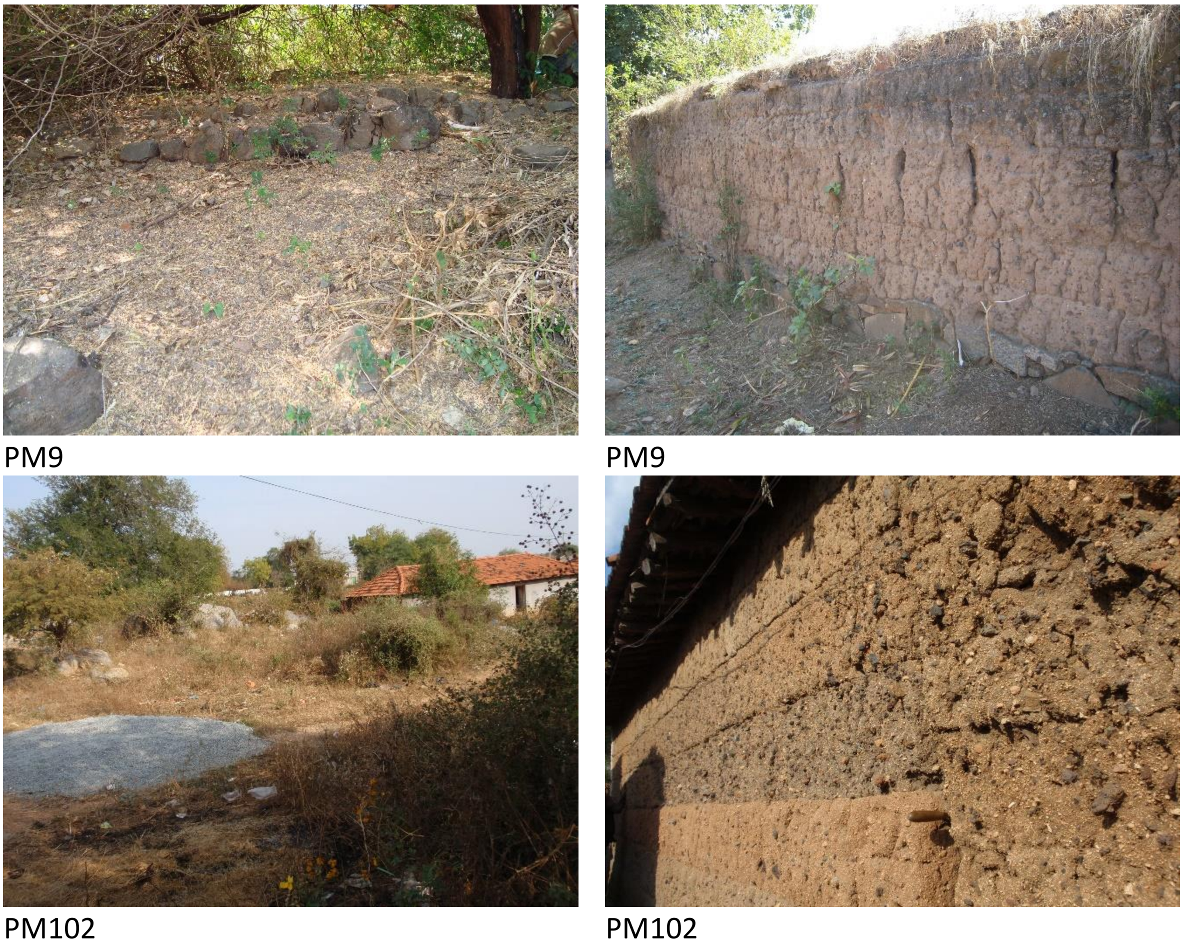


Figure 5.24 – Small mound of technological debris at PM9 (top left), the mudbrick walls with metallurgical waste grog at PM9 (top right), the large open area with material scatter at PM102 (bottom left) and the mudbrick walls with metallurgical debris grog at PM102 (bottom right).

The remaining eight sites were found within agricultural land and are mostly very poorly preserved. Sites **PM58**, **PM63**, **PM84**, **PM87**, **PM91** and **PM128** are almost entirely destroyed, consisting of large quantities of scattered material within agricultural fields (Figure 5.25). This material presumably came from former metallurgical waste heaps which were undoubtedly levelled to leave room for agriculture. The size of the scatters vary considerably with the largest c.80m across.

PM54 consists of one well preserved waste mound in a field corner south of Kalleda, Karimnagar district. This deposit runs roughly east-west and survives to a height of c.2m and c.4m wide. Another less well preserved mound was identified in an adjacent field with significant surface debris scatter. At **PM88** (close to Nambal, Adilabad district) there is a partially surviving waste heap, c.18x8m. It is orientated east-west with a maximum height of 1.5m (Figure 5.25). This heap is adjacent to remnants of another heap which survives partially as an enlarged field bank standing 1m high and 1.5m wide (Figure 5.25). Greater concentration of material on the field boundaries was also noticed at most of the other sites, perhaps because the material makes for sturdy field banks or perhaps due to the fact that these areas are not ploughed (disturbed) as much.

Of special interest are the surface scatters found at **PM58** and **PM128**. Similar to some of the better preserved sites discussed above, the scatters of material appear to be segregated by technology. The material scatter at **PM58** has more crucible remains on its eastern side and a relative absence of crucible fragments on the western part. The same is true at **PM128** where the large scatter, some 50-60m across, has more crucible remains on the eastern side. Although these sites are poorly preserved, it once again strengthens the idea that crucible steel manufacture and iron smelting production were segregated on site even though they probably operated simultaneously.

PM63

PM84

PM88

PM88

Figure 5.25 – Dense material scatters at PM63 (top left) and PM84 (top right), the waste heap at PM88 (bottom left) and the large field bank mostly composed of metallurgical waste at PM88 (bottom right).

5.1.4.3 Smelting Sites

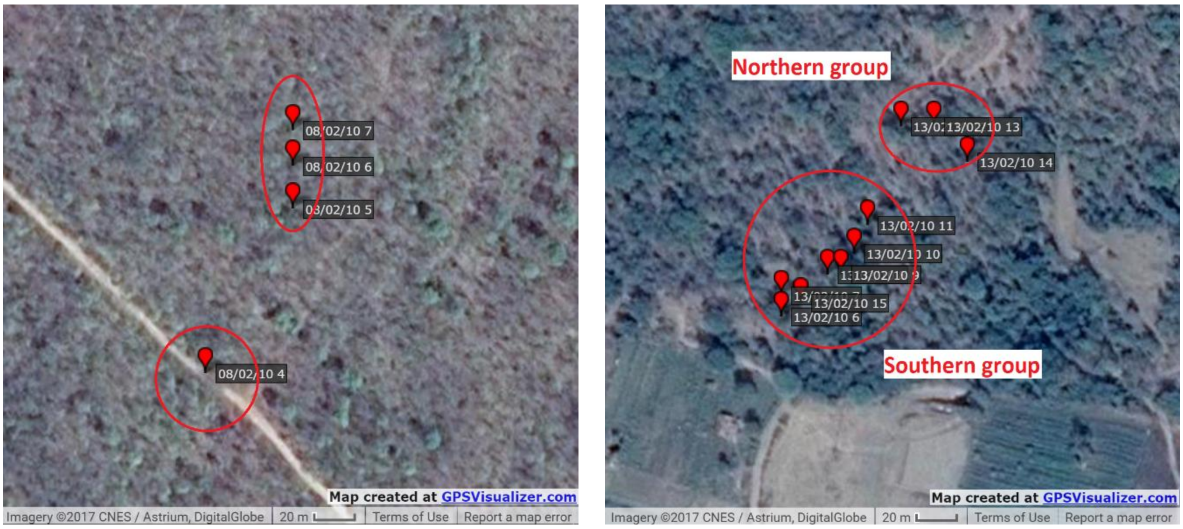
By far the largest group of metallurgical sites were those which only show evidence for smelting. In total 78 of these sites were recorded. None have evidence for crucible steel manufacturing. The observed smelting remains are mostly slags (tap and furnace) mixed with furnace wall and tuyeres fragments (see chapter 6). The sites are wide ranging in terms of size, preservation and location setting suggesting a widespread and diverse technological origins. It is also important to mention that in the core research area, the majority of villages showed past metallurgical activity either within, on the edge or in the immediate surrounding agricultural landscape. Due to the large number of sites, they cannot all be individually described here but more detailed information on the individual sites and locations can be found in appendix A. Since the sites do vary significantly in terms of size, preservation and setting, the better preserved sites will be described in more detail first, followed by the general trends of the less well preserved examples.

Forest Sites

The sites showing the least degree of disturbance were those found within forests where human activities have been kept to a minimum. It is important to mention here that although four sites (**PM56**, **PM79**, **PM80** and **PM112**) were recorded within dense teak forest, these are relatively recent plantations and probably did not exist when the smelting activities took place (Jaikishan pers. comm., 2010). This is supported by the fact that some of the trees are growing on top of the metallurgical waste mounds themselves. Due to their good preservation, they may give clues as to what the other, less well preserved sites may once have looked like. On the other hand, the opposite may be true and due to their isolation, they may be distinctive and represent a different smelting technology from sites found in agricultural and settlement settings. This section will deal exclusively with general smelting site descriptions. The detailed examination of the material, assessment of trends and identification of technologies are dealt with in the next two chapters (6 and 7).

All four sites are large and similar in layout. They comprise multiple discrete waste mounds of varying size, usually aligned and in close proximity. **PM56** close to Nawabpet, Adilabad district for example, consists of one large irregular shaped mound bisected by a road (Figure 5.26). The southern half measured c.45x25m, while the northern part measured c.25x25m with the deposits being at least 2m in height (Figure 5.27). Unfortunately, due to time constraint and the nature of reconnaissance survey, the whole site was not fully surveyed but it appears to have been aligned with several smaller sub-circular undisturbed mounds, c.25m in diameter, heading in a north-north-eastern direction into the forest (Figure 5.26). **PM79** close to Davanally, Karimnagar district, is also similar, comprising two waste heap groupings (Figure 5.26). The southern grouping consists of six small mounds, c.5m apart and aligned south-west – north-east, spanning an area c.60-70m in length, c.20m wide and c.2m in height (Figure 5.27). The second mound grouping was situated c.40m north of the southern mounds and consisted of three to four circular/oval heaps c.5-10m wide, encompassing an area c.40-50m in length on a north-west – south-east alignment.

PM80 close to Kairigudam, Karimnagar district, shows similarities with the other forest sites and comprises three undisturbed waste heaps varying in size from c.10x6m, 1m in height to c.30x40m with a maximum height of 3m, roughly clustered on a north-south alignment extending over 90m (Figure 5.27). **PM112** close to Bornapalli, Karimnagar district, comprises five small, undisturbed circular waste heaps, c.10-15m in diameter, with a c.5m spacing between each. They form a clear north-south alignment covering a length c.100m. There is evidence for more heaps to the west but these appear to have been cleared and levelled, possibly used as road ballast.



PM56 PM79

Figure 5.26 – Distribution of debris mounds at PM56 (left) and PM79 (right).


PM56

PM56

PM79

PM79


PM80

PM80

Figure 5.27 – Metallurgical waste heaps in the forest sites PM56 (top images), PM79 (centre images) and PM80 (bottom images).

It is interesting to point out that sites **PM79**, **PM80** and **PM112** are all very close, encompassed in an area c.5km in radius. **PM56** is also relatively close, situated c.13km north of this grouping. The similarity of the sites as well as their relative proximity suggests that similar smelting technologies were employed, even perhaps by the same group of people. In support of this, are three *in situ* furnace remains found at these sites showing close parallels in construction and layout. One was found at **PM79**, situated at the base of one of the southern mounds. The furnace consisted of roughly shaped granitic rocks arranged in a circle with a degraded and partially collapsed clay lining interior (Figure 5.28). Clearance of leaf litter and loose material revealed a large piece of smooth tap slag (c.450mm long and c.160mm wide) still in positon just outside the furnace opening, as well as a large furnace bottom cake at the base of the furnace (500x300mm). Immediately to the north of the furnace was a paved area, c.600x450mm, consisting of smooth, flat stones as well as a larger protruding stone set upright in the ground (Figure 5.28). The two others were found at **PM80**, located between two waste mounds. These show close parallels with the furnace recorded at **PM79**, mainly composed of a degraded clay circular structure, c.0.6m in diameter, with similar granitic stone elements (Figure 5.28).

PM79


PM79

PM80


PM80

Figure 5.28 – In situ furnace found at PM79 (top images) and the furnaces found at PM80 (bottom images). Note the similarity in size and layout of the stone elements.

Primary smelting sites

Seven (**PM3**, **PM28**, **PM52**, **PM72**, **PM92** and **PM100**) other primary sites were recorded with minor to no disturbance. These, like the forest sites discussed above, comprised a single or multiple metallurgical waste heaps. Approximately half of the sites were located in bare scrubland while the other half were found in agricultural settings. For the most part, the mounds were covered in dense, low lying shrub vegetation.

Two interesting sites are **PM3 and PM72**. These are both located on bare scrubland at the base of large granitic hillocks. **PM3** situated close to Buggaram, Karimnagar district, comprises a singular large sub-circular metallurgical waste mound, c.40m in diameter and c.3m high (Figure 5.29). It is relatively well preserved except for some modern quarrying at its deepest part. There is also scattered material to the north which may have come from this site. The exposed section of a modern water-retention trench shows evidence for a collapsed furnace, suggesting that the furnaces may have been located directly upslope of the main deposit. Of particular interest is an area c.50m south of the main deposit which has a cluster of possible grinding holes and hollows on the flat surface of an extensive granite outcrop (Figure 5.29). These are mostly elliptical, varying in depth (0.6m max) and orientation. Many appear angled as if grinding from one side with internal black and red oxide staining.

PM72 situated close to Maddunur, Karimnagar district, is comparable with a large mounded deposit, c.30m in length, c.12-15m wide and c.1-2m deep, on the north-eastern side of a large hillock (Figure 5.29). The remains here are relatively undisturbed and lie on an exposed flat granite platform. Similar to **PM3**, adjacent to the deposit are several elliptical hollows in the granite with a reddish staining (Figure 5.29). Although their function remains uncertain, it is possible that they could have been used for processing (grinding or crushing) iron ore. It is also interesting to point out that these two sites are relatively close to one another, **PM72** being only c.4km east of **PM3**. Similar technologies might have been used at both sites, perhaps by the same group of people and may be similar in date.

Figure 5.29 – In situ material heaps at PM3 (top left) and PM72 (bottom left) as well as the potential ore preparation pits at PM3 (top right) and PM72 (bottom right).

The largest primary site is **PM100**, situated c.250m south of Chittial village, Adilabad district. This site comprises of three large, well-preserved mounds of technological debris spaced c.150m from each other in bare scrubland and agricultural fields. The three heaps are either sub-circular or elliptical in plan, ranging from 30-60m in length with a depth of 2-3m (Figure 5.30). On the whole, these mounds are undisturbed but the agricultural fields have encroached on the two most southern heaps. **PM28** is also relatively large, consisting of a large mound of technological waste bisected by a main road, 500m south of Mallapur village, Karimnagar district (Figure 5.30). The heap is well preserved but it has been disturbed on the eastern side of the road by agricultural fields. The remains point to a mound c.90m in length, c.50m in width with a maximum height of 3.5m. The other two sites (**PM52** and **PM92**) have smaller heaps, ranging in size from c.15x6m and 2m high at **PM52** (Figure 5.30) to c.45x25m and 1m high at **PM92**. The heaps found at **PM52** form large field boundaries and have been encroached upon by the agricultural activities. **PM52** is in close proximity to smelting site **PM51** which was only recorded as scattered remains.

PM100

PM100

PM28

PM52

Figure 5.30 – Northern-most (top left) and southern-most (top right) residue mounds at PM100, the large heap at PM28 (bottom left) and the remains at PM52 (bottom right).

Disturbed smelting sites

The majority of the smelting sites recorded were disturbed. The degree of disturbance varied significantly, with some sites retaining parts of their primary waste heaps while others were almost completely destroyed, leaving only scattered remains. Twenty-seven partially disturbed sites with remaining heaped remains were recorded. The majority of these were located within agricultural fields/plantations (**PM11**, **PM30**, **PM39**, **PM40**, **PM42**, **PM46**, **PM47**, **PM48**, **PM57**, **PM76**, **PM77**, **PM93**, **PM99**, **PM118** and **PM129**) while the others were located on village edges, on the boundaries of settlements and agricultural or bare scrubland (**PM24**, **PM44**, **PM45**, **PM49**, **PM61**, **PM73**, **PM74**, **PM82**, **PM83**, **PM113**,

PM120 and **PM132**). Due to the large number of sites, they cannot be described individually, so the general trends will be assessed and some of the larger sites will be described in more detail.

All of these sites have heaped metallurgical material partially surviving. The majority have been partly levelled to leave way for agricultural cultivation, primarily paddy fields but also cotton, chilli and mango plantations. The heaps have survived partially on the edges of fields, often being incorporated within field boundaries or banks. Where this is the case, there is also large amounts of scattered material within the fields themselves. Several sites (**PM30**, **PM39**, **PM46**, **PM74**, **PM82**, **PM99**, **PM113** and **PM120**) have been disturbed or bisected by road construction, with the heaped remains often surviving on the boundary between roads/tracks and adjoining agricultural fields or settlements. Due to the high degree of disturbance, often leaving only a small fraction of the metallurgical remains intact, the deposits vary. Some sites (**PM11**, **PM39**, **PM47**, **PM48**, **PM73** and **PM76**) are relatively small, with remains less than 20m maximum dimension. However, most comprise of a singular large mound between 20-50m in length and 0.5-2m in height. Only a few sites are larger with multiple heaped remnants.

PM40 for example, comprises two heaps. One is sub-rectangular, c.40x30m in size and 1-2m in height, while the other is thin and elongated, c.38m long, c.5m wide and 1.5-2m in height. The larger, rectangular heap has a flattened top, being used now for bean cultivation. It is also interesting that **PM40** forms a cluster of sites (within a 900m diameter) with **PM38**, **PM39** and **PM42**, which are all north of Lachakkapet, Karimnagar district (Figure 5.31).

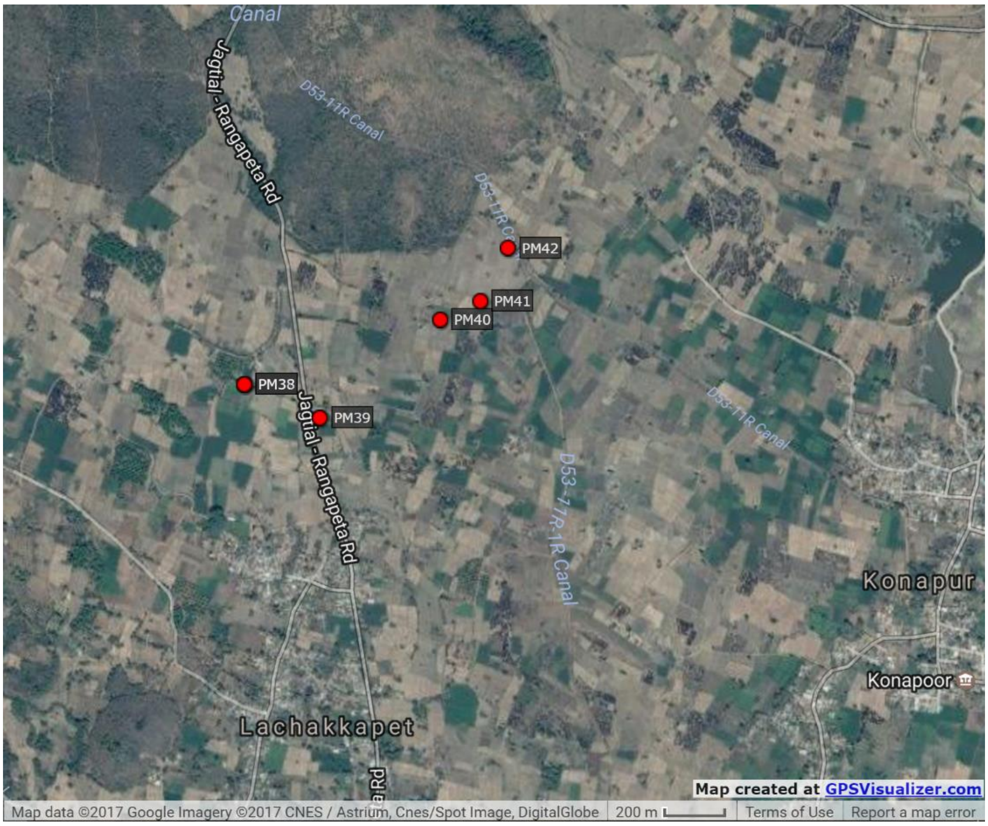


Figure 5.31 – Location of PM38, PM39, PM40 and PM42 grouping, north of Lachakkapet village.

PM44 comprises two large mounds located on the edge of Rangapeta village, Karimnagar district. The largest of which is c.80x40m in size and 4m in height but is disturbed by the settlement to the north and fields to the south. **PM46** consists of three large mounds situated c.200 metres north-east of Uppumadugu village, Karimnagar district. Two of the mounds are adjacent to one another, both c.30x20m in size and 1.5-4m in height (Figure 5.32). The third mound is c.60m in length and c.1.5m in height, running parallel and adjacent to a main road. It appears that it could be the remnants of a much larger mound disturbed by road construction.

Figure 5.32 - Two adjacent mounds at PM46, north-east of Uppumadugu village.

PM74 is one of the largest sites recorded, with three large surviving waste mounds. As discussed above, it is also associated with the crucible/smelting site **PM75** and together they form the largest metallurgical complex recorded (Figure 5.18). The site is located on bare scrubland and agricultural fields on the edge of Parasurampalli village, Warangal district. The main deposit is c.75x50m in size and up to 4m in height but it appears to have been recently quarried for road construction which has left a huge gouge through the centre of the mound (Figure 5.33). To the north of this main deposit are the remains of two other mounds, c.60x50m and c.40x45m in size, but they have also been heavily disturbed and partially levelled by agriculture and the road running parallel to the village (Figure 5.33). Smelting waste was also found further south-west but the majority of the material appears to have been removed.

Another large site is **PM77**, situated c.350m west of Rangasagar village, Karimnagar district, within agricultural fields. It consists of three mounds, two of which are adjoining, less than 15x10m in size and heavily disturbed by cultivation. The larger heap is c.45m long and up to 1.5m in height, forming a large field boundary (Figure 5.33). **PM129** is also large, the heap forming the boundary of an extensive mango plantation and extends over 100m in length but only survives to a relatively low height.

PM74


PM74

PM77

PM77

Figure 5.33 – The main deposit (top left) and one of the northern most mounds (top right) at PM74 as well as two mounded deposits at PM77 (bottom images) forming part of field boundaries.

A further 26 smelting sites, recorded within agricultural land, bare-scrubland and close to villages, were almost entirely destroyed or levelled, leaving only material spreads of various densities. The majority of these sites (**PM10**, **PM31**, **PM51**, **PM64**, **PM70**, **PM85**, **PM90**, **PM94**, **PM95**, **PM97**, **PM98**, **PM104**, **PM110**, **PM111**, **PM115**, **PM116**, **PM117**, **PM127**, **PM130**, **PM134** and **PM137**) were levelled to make room for agricultural activities. Their remains were spread throughout field systems (Figure 5.34), often showing greater densities of material on their boundaries or banks where it accumulated. In a few instances, where the sites were situated on village edges (**PM108**, **PM123**, **PM125** and **PM127**), mounds were also levelled to give way for new constructions or the expansion of the settlements (Figure 5.34). Another common destructive factor was the building of roads. Sites adjacent to roads (**PM10**, **PM94**, **PM95**, **PM96**, **PM115**, **PM116** and **PM135**) were often levelled or quarried to use as ballast (Figure 5.34). The extents of the material spreads at each site were not always recorded, but those that were, show that they varied from 20x20m to 100x70m in size, with scattered surface remains typically less than 0.1m in depth. In addition to the levelled sites, are two secondary sites (**PM35** and **PM38**), comprising of material which was not *in situ* but brought in from another location. **PM38** consists of metallurgical waste observed as grog within the mud fort **PM37**. Since none of these disturbed sites reveal much on the original size, layout and nature of the deposits, they will not be discussed any further here.

PM64


PM85

PM97


PM108


PM95


PM135

Figure 5.34 – Scattered material remains spread within field systems at PM64 (top left), PM85 (top right), PM97 (centre left), a thin scatter of material disturbed by the settlement at PM108 (centre right) and material heavily disturbed by road building at PM95 (bottom left) and PM135 (bottom right).

Village sites

In addition to the sites discussed above which were predominantly located within agricultural land, 12 smelting sites were recorded within villages. Of these, eight are disturbed (**PM8**, **PM14**, **PM22**, **PM26**, **PM27**, **PM34**, **PM69** and **PM124**) while four are secondary (**PM21**, **PM50** and **PM126** and **PM131**) with material not in its original location. Three of the secondary sites are all material found in mud house or compound walls with no evidence of any main deposit in the vicinity, making it likely that the material was brought from elsewhere. The small mound at **PM50** is material which has clearly been moved and mixed with modern tile fragments.

All village sites are very disturbed and primarily comprise small, low mounds that have been partially levelled or incorporated into the walls of houses and compounds. Sites **PM22** (Narella village) and **PM124** (Gangapur village) only consist of sparse scatters less than 50m maximum dimension, visible in between houses and compounds (Figure 5.35). **PM8** is located in the centre of Sirikonda village, Karimnagar district, and, as mentioned above, is close to smelting/crucible site **PM9**. The remains of a small, low mound were observed with surrounding scatter (Figure 5.35). At **PM14** a small mound c.10x10m, with a surrounding scatter of material, c.30m maximum dimension, were found in a house garden situated in the centre of Shekalla village, Karimnagar district. A larger disturbed mound up to 2m in height with a surrounding scatter was observed at **PM26** in the northern part of Arnakonda village, Karimnagar district (Figure 5.35). In the southern part of the same village is **PM27** which is the remains of another small heap, but the material is also mostly scattered. It is important to mention that a better preserved site (**PM24**) was found on the northern edge of the village, approximately 150m north-west of **PM26**. In the northern part of Kammarikhampet village, Karimnagar district, two small mounds were observed, each <11m wide, forming **PM34**. The mounds (<1m in height) and scattered debris were incorporated into the drystone walls of house compounds. Another similar, small disturbed mound was recorded at **PM69** in the southern part of Nagaram village, Karimnagar district. It is linear, c.6m in length, and forms part of a rough wall of a modern house compound. Most of the heaped waste is no more than 0.3m in height but large boulders have been placed on top (Figure 5.35).

PM22

PM8

PM26

PM69

Figure 5.35 – Scattered remains at PM22 (top left), the small mound at PM8 (top right), the larger deposit at PM26 (bottom left) and the disturbed low heap forming part of a compound wall at PM69 (bottom right).

5.2 Analysis of Metallurgical Site Records

5.2.1 Nature of Metallurgical Sites as a Whole

The general characteristics of the metallurgical sites surveyed will be assessed and discussed in this section. Descriptions of each site were documented, including their general size, deposit depth and state of preservation as well as a record of the setting in which they were found. This information was formalised into a set of defining characteristics, facilitating comparative analyses of sites and site types. The methods for assigning the descriptive categories for site size, depth of deposit, preservation status and setting are discussed in more detail in chapter 4.1. It is important to note that the assessment of collected technological waste from each metallurgical site will not be the focus here. Refer to chapters 6 and 7 for assemblage typology and technological resolution.

To facilitate understanding, a brief summary of each site characteristic will be provided here. All descriptions were a qualitative measure based on surface observation. Site size was recorded as small (sm. = $<25m^2$), medium (med. = $25\text{-}100m^2$) and large (lg. = $>100m^2$). Deposit depth as shallow (sh. = <0.1m), medium (med. = 0.1-0.5m) and deep (>0.5m). Preservation status as primary undisturbed (prim.), primary disturbed (dis.) and secondary (sec.). Location settings were noted as A (agriculture), BS (bare scrubland), F (forest), S (settlement) and SE (settlement edge). Some sites were spread across more than one setting and were hence ascribed more than one location category. For example, a site that extended from a settlement edge into the surrounding agricultural land was assigned SE-A.

On the whole it is clear that in terms of size, the greatest majority of sites (73%) fall in the large category (Figure 5.36), where the archaeological and technological remains cover an area greater than $100m^2$. Small and medium sites account for 5% and 12% of the record respectively (Figure 5.36). At the outset it is seems to suggest that many sites have a significant amount of technological debris, suggesting intensive industrial activity over possibly long lifespans. However, it is also clear that the majority of sites are disturbed (81%), many composed of scattered material (Figure 5.36). This ranges from partial disturbance where part of a heap of material has been quarried or scattered, to levelling of an entire deposit of material usually to make room for agricultural or building activities. In the latter cases, the original size of the deposits is not possible to determine, so they were classified by the size of the spread. This situation is also reflected in the depth records of the material waste, with over a third (36%) of the sites recorded as shallow and 15% as medium (Figure 5.36). These two groups inevitably represent the very disturbed sites where material is scattered, leaving only a layer of debris on or just below the surface. Indeed, all sites with shallow deposits are either heavily disturbed or secondary sites.

Only 13% of the sites recorded were primary, undisturbed sites (Figure 5.36). The fact that so few sites are undisturbed is certainly attributable to the increased human impact on the environment and more intensive land use in the region in recent times. As was stressed in chapter 3, rising population density combined with increasing economic development causes greater pressures on the land through the expansion of settlements and more intensive agricultural exploitation. Hence, areas where past metallurgical activities took place are now being reclaimed, inevitably leading to the destruction of the archaeological evidence. The recorded location settings of these sites do indeed reflect this trend. The majority of the sites are located either within agricultural land (44%), settlements (17%) or on the edge of settlements (31%) (Figure 5.36). Sites located on still unused bare scrubland or in forests account for a minority (8%) (Figure 5.36). However, it is not surprising that despite making up the minority of sites, these location settings constitute over half (54%) of the primary undisturbed sites. All sites recorded within forests and 75% of those found on bare scrubland were ascribed as primary undisturbed. Others were found within field systems, often used as field boundaries, or as surviving mounds of debris within larger agricultural tracts. It is also important to mention that all primary undisturbed sites are large in size with deep deposit depths. Only six sites (6%) were recorded as secondary (Figure 5.36) with evidence of technological material but heavily disturbed and not in their original location. It is significant that four of these were within settlements where human activity and disturbance by construction is greater, while the other two were in agricultural fields. Therefore, modern human activities and site setting have a direct impact on certain site characteristics, most notably size, preservation status and deposit depth.

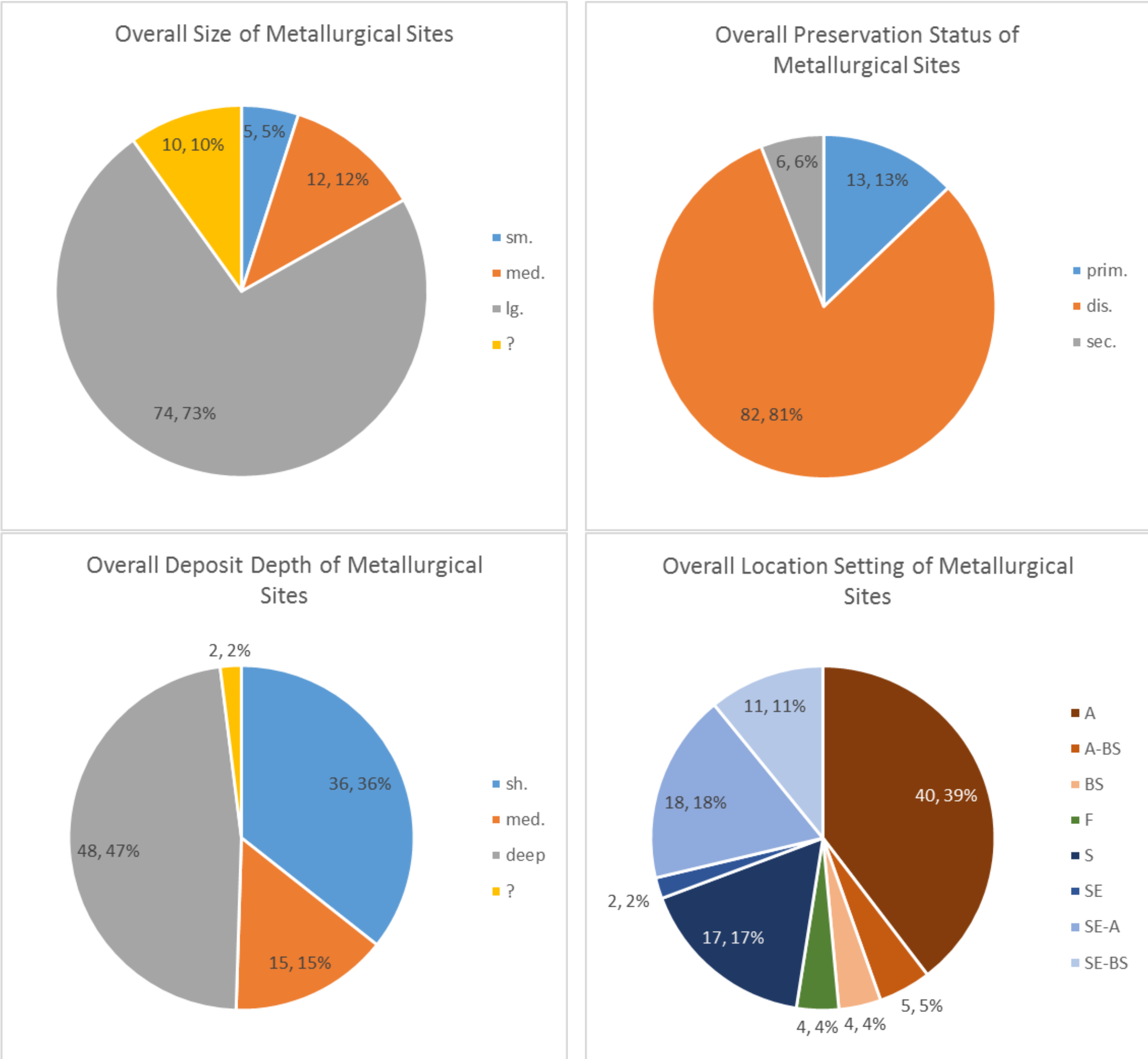


Figure 5.36 – Quantification of all metallurgical site records by size (top left), preservation status (top right), deposit depth (bottom left) and location setting (bottom right). Note - ? are unrecorded.

The fact that the majority of sites are not within settlements is in itself significant in other ways. Several possibilities could account for the marginalisation of these activities to the peripheries or outside settlements. It is possible that sites were located closer to the natural resources required for the production of iron or steel, primarily iron ore, clay or fuel (wood charcoal). However, these materials appear to have been abundant in the vicinity of most settlements, so another explanation is possible. Perhaps more space was required for the activities than was available within settlements but, if so, one might expect more of them to be located on settlement edges. Another possibility is the social status of the workers who manufactured iron and steel. It is possible that they occupied lower social positions than other groups within these settlements. As was briefly introduced in chapter 3.2, households belonging to the higher stratas of society are usually located centrally within settlements, while those of lower status are mostly limited to the peripheries. Therefore, if this was the case, their activities would certainly have been marginalised and pushed to the edges or beyond core settlements. In addition, it could also suggest an itinerant workforce who may have travelled to exploit resources until they were depleted or that moved based on consumer demand. Although important, it is not possible to positively attribute within the scope of this study one reason for the location setting trends of metallurgical activities, especially since a mixture of factors could have contributed. It is also likely that there was a variation of factors in different parts of the region under study or indeed at different times. The social aspects of metallurgical production, use and trade is the subject of another PhD research project by Neogi (Neogi forthcoming).

5.2.2 Analysis by Site Type

Having outlined the major site characteristics, it is now important to assess site type trends by deposit size, deposit depth, preservation status and setting. To reiterate, smelting sites are dominant, accounting for 77% of the total site records. Smelting/crucible sites with predominant smelting waste and crucible or crucible/smelting sites with predominant crucible steel waste form a minority of the total site records, each accounting for 9% and 14% respectively.

Site size represents the extent of their deposits by area. Figure 5.37 shows the number and proportion of sites within each site type by size of deposits. There are no major trends observable, with the majority of sites being large. Perhaps not surprisingly, due to the larger sample size, the smelting sites show the greatest variation with few small, some medium and many large sites (Figure 5.37). The majority of the crucible/smelting sites are also large with only one site being small (Figure 5.37). This site is the only site dedicated to crucible steel without evidence for smelting, but as mentioned earlier, it might be associated or indeed part of the larger crucible/smelting sites found in the same village. As a whole, site size is limited by the irregularity of site preservation and deposit depths. Hence, size is not always representative of the amount of technological material present and scale of metallurgical operations.

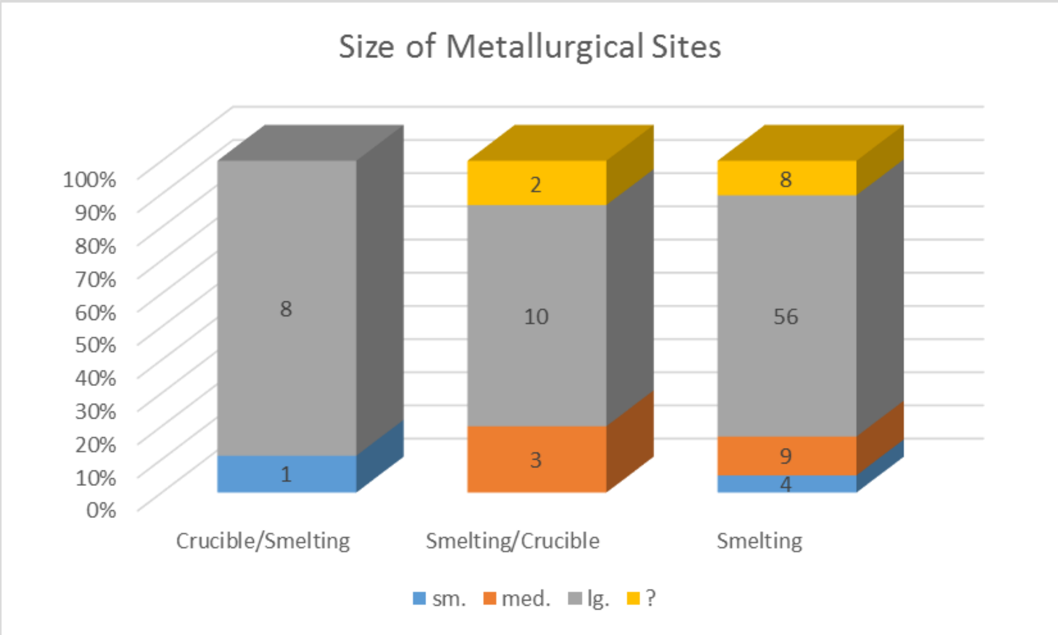


Figure 5.37 – Number and proportion of sites within each site type by size of deposits. Note - ? are unrecorded.

The number and proportion of sites within each site type by preservation status is shown in figure 5.38. The proportion of preservation status is similar in all three site types. Approximately 7-14% of each site type are primary sites with little to no disturbance, whereas the majority 78-93% are disturbed (Figure 5.38). All of the six secondary sites fall within the smelting grouping, accounting for almost 8% its total (Figure 5.38). Hence, preservation status is not directly correlated to the type of metallurgical activities present on sites. As suggested previously, it has more correlation with the location setting of the sites and the degree of human interference in those settings.

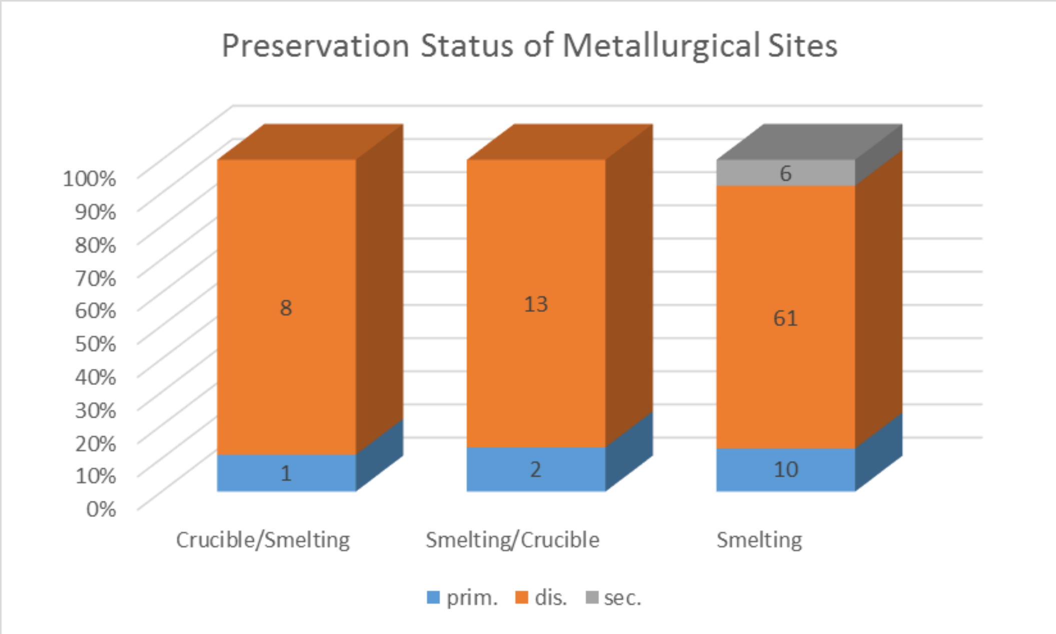


Figure 5.38 – Number and proportion of sites within each site type by preservation status.

The more interesting trends are seen in their deposit depth and location setting data. On the whole, the crucible/smelting sites appear to have deeper deposits with around 56% of sites being more than 0.5m in depth, while 22% and 11% of the deposits are medium and shallow respectively (Figure 5.39). The smelting/crucible sites almost have an equal representation of shallow, medium and deep deposits, with each accounting for approximately a third of the total (Figure 5.39). The smelting sites on the other hand, have the largest proportion of shallow deposits, making 39% of the total. This is probably due to the fact that almost half of the disturbed smelting sites were completely levelled, only leaving shallow scatters of material. The majority of the rest are deep (48%) while only 11% of the sites have medium deposit depths (Figure 5.39). Although there is some variation in deposit depth between site types, this is more likely due to their overall preservation status and location setting than operating technology type. For example, sites within agricultural land are more likely to have been levelled to make way for agriculture.

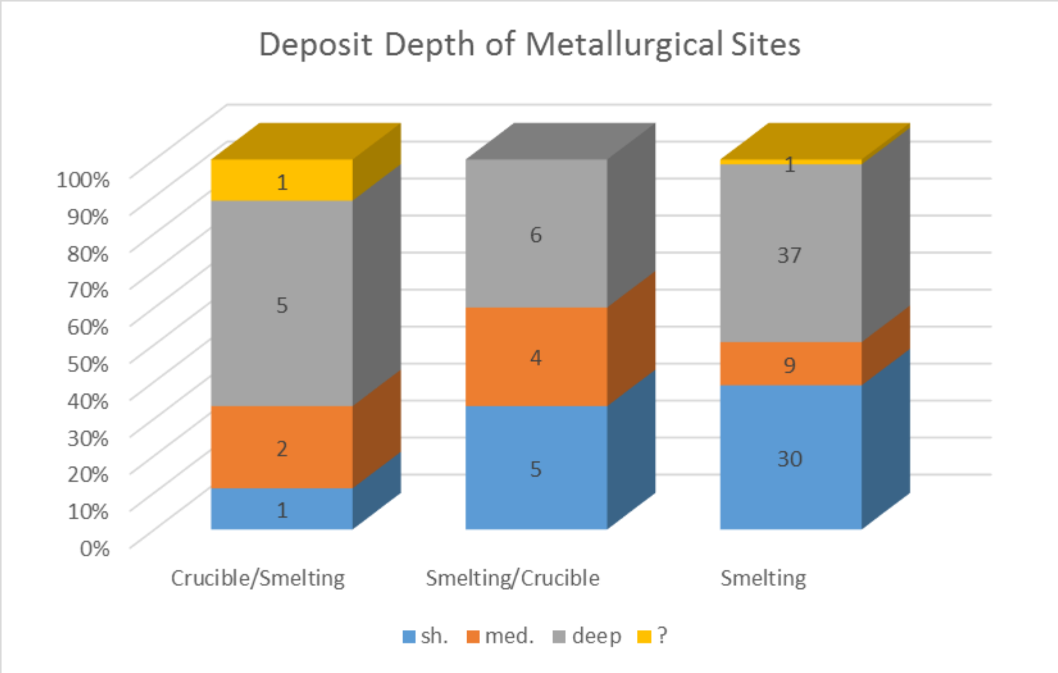


Figure 5.39 - Number and proportion of sites within each site type by deposit depth. Note - ? are unrecorded..

Location setting data provides the most relevant trends. Figure 5.40 shows the generalised location settings in which the sites were found, characterised by site type. The majority (78%) of the crucible/smelting sites are located within or on the edges of settlements, while only two sites (22%) were located in agricultural land (Figure 5.40). Although these two sites (**PM62** and **PM75**) were within agricultural fields, they were still <400m from the nearest settlement. Smelting/crucible sites are almost evenly split between sites located in agricultural land (53%) and those found in settlements or settlement edges (47%) (Figure 5.40). The smelting sites on the other hand, are found in much more varied location settings. A good proportion (39%) are within agricultural cultivation, while another 12% are found in a mixture of agricultural and bare scrubland environments. The majority of the rest (44%) are found in settlements or settlement edges (Figure 5.40). The four forest sites recorded are also smelting sites and due to their remote locations, tend to be some of the best preserved metallurgical/technological remains.

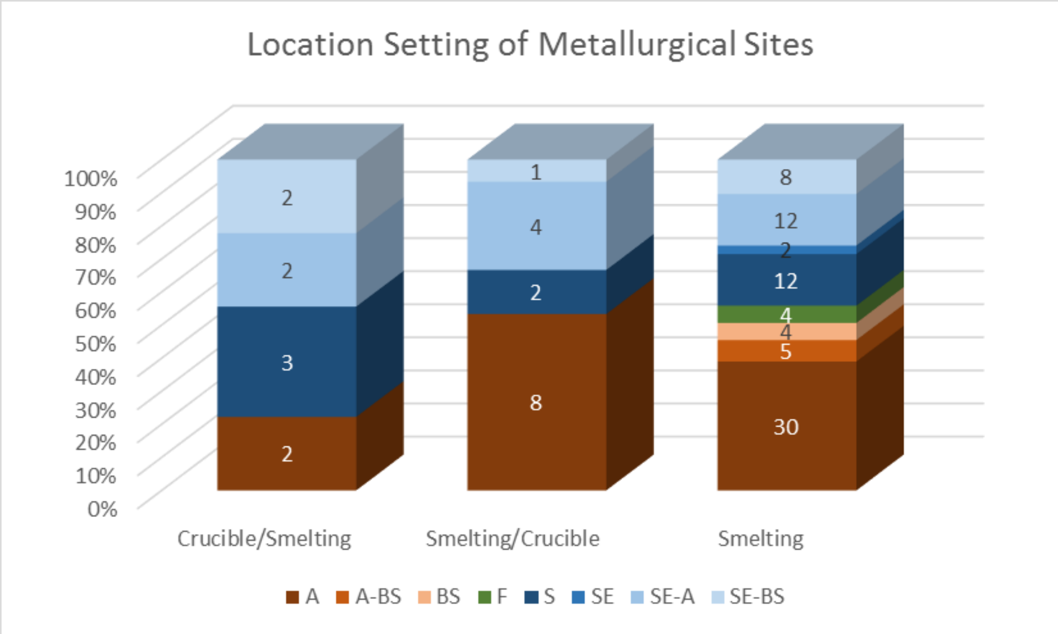


Figure 5.40 - Number and proportion of sites within each site type by location setting.

Thus, sites with evidence for crucible steel production have a greater tendency to be located within or near settlements, while sites with iron smelting production are more varied, and in many cases far from any observable human habitation. It can be concluded that crucible manufacture was more centralised, perhaps requiring a larger workforce and hence tended to be based in and around settlements. It may also have been subject to greater control or management by the end user, local authorities, merchants and traders. This might have required the metallurgical activities to be closer to the markets or administrative control of larger settlements. Another possibility is that iron smelting and crucible steel were controlled by different groups of people, perhaps of different social status. This could have placed limitation on areas where certain social groups where allowed to operate. It is conceivable that crucible steel production, due to its remarkable properties (chapter 1), was seen as more prestigious than common iron or steel production. This higher social status would have been reflected upon the artisans that produced it, allowing them to work within or close to settlements. Another important factor to consider, is the inter-relationship between smelting and crucible steel production. Iron smelting undoubtedly produced some of the feedstock for crucible steel. Therefore, these may have been situated closer to natural resources outside villages while crucible steel, a more specialised technology, was centralised in and around settlements.

Numerous reasons could account for the trends observed but resolution is not possible at this stage. The assessment of the waste material observed and collected from these sites in the following chapters should help identify more specific technological types which could enlighten some of these trends. Site characteristics in relation to individual technological groups are re-assessed in chapter 7.4. What is certain is that the archaeological record in Telangana proves that metallurgical production in the past was varied and complex. This variation could be both spatial and temporal.

5.2.3 Spatial Distribution of Site Types

The geographical site locations were plotted on a map to assess spatial distribution by site type (Figure 5.41). The majority of sites recorded lie in the core research area, north-western Karimnagar, southern Adilabad and eastern Nizamabad districts. A few outliers in south Karimnagar and in Warangal district were also surveyed.

No major spatial distribution trends are noticeable between metallurgical sites of different types. With the exception of the outliers, which were targeted due to their known crucible steel manufactures, all smelting and crucible steel sites are randomly distributed within the core research area. The distribution of crucible steel sites shows that the technology was more widely distributed than previously known. Previous work focused on one site, Konasamudram (Figure 5.41), with little information available on other manufacturing sites. It is now possible to say that crucible steel was produced in many parts of Northern Telangana and Konasamudram forms one of many sites in the region, part of a wider metallurgical tradition. Spatial distribution is re-assessed in chapter 7.4 when more specific technological groups and variants have been identified based on the macro-morphological analysis of the material remains.

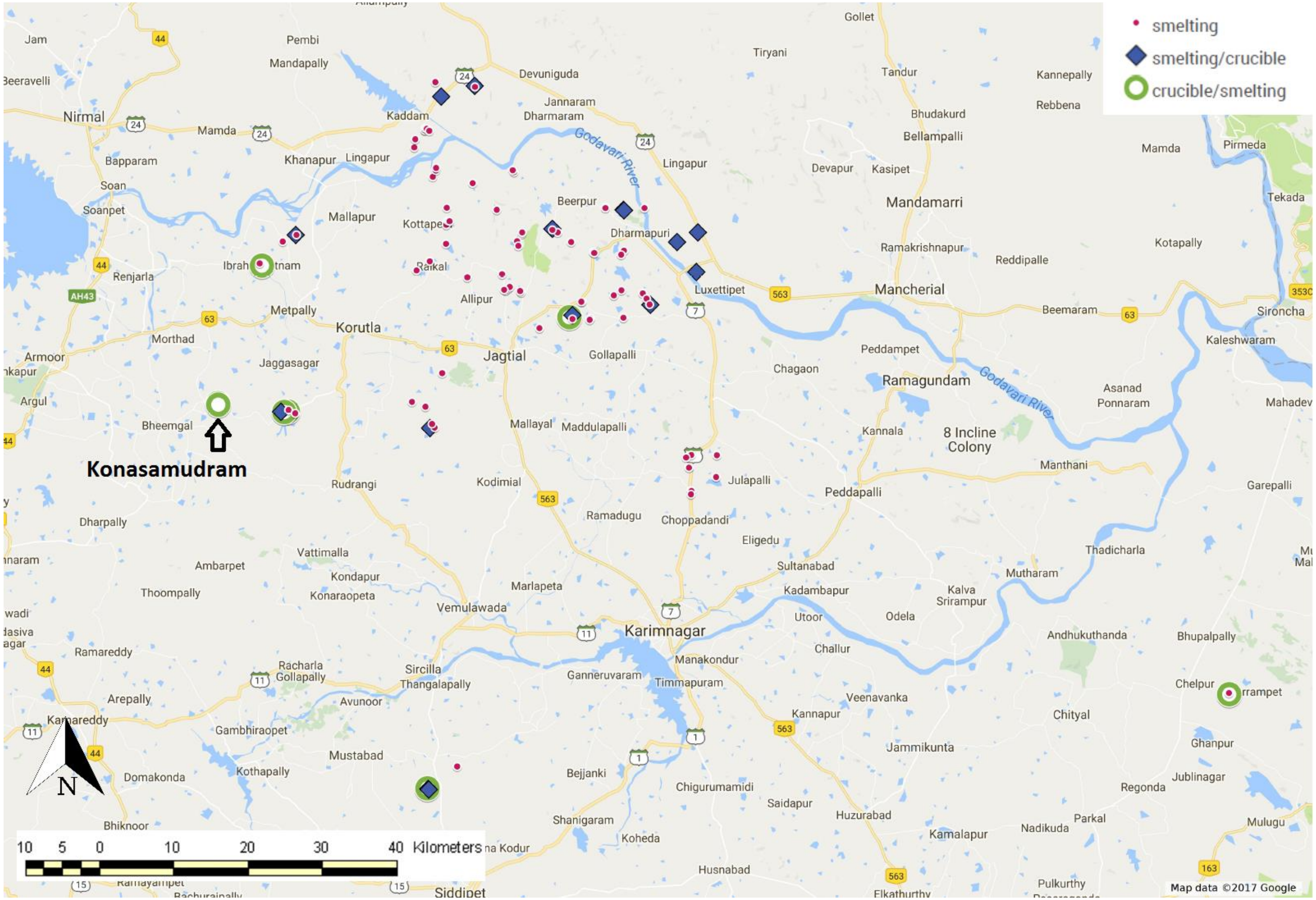


Figure 5.41 – Location of metallurgical site types, smelting, smelting/crucible and crucible/smelting.

5.3 Conclusion

The 139 sites recorded during fieldwork were characterised, described and their general size, depth, preservation and location setting trends analysed. The sites were broadly characterised into four groups - historic, geological, ethnographic and metallurgical sites. The historic sites included several ancient settlements, temples, forts, individual structures and prehistoric sites. Although these did not represent the core of the research undertaken, they do attest to the longevity of human habitation and intensive land use in the region. The geological sites were grouped into iron ore sources, quarries and mining pits. These showed that the region had a plentiful and easily accessible supply of banded magnetite iron ore, suitable to sustain the metallurgical activities. The ethnographic sites were all blacksmith workshops. Their almost identical layout and similar operating procedures attest to the uniformity and high level of technological know-how throughout the research area. It also suggests a long-lived tradition of manipulating iron and steel implements which has now been uniformly standardised.

The core of the research comprises the 101 metallurgical sites recorded. These were characterised into three groupings based on the predominance of material waste resulting from iron smelting and crucible steel production. These groups are crucible/smelting, smelting/crucible and smelting sites, the first category comprising the dominant technological waste material observed at those sites. Crucible/smelting (9%) and smelting/crucible (14%) sites made up a minority of the site records with the largest proportion being remnants of iron smelting (77%). The fact that no identified sites had evidence for crucible steel production only is significant. All crucible remains were found mixed with varying proportions of smelting debris, suggesting that both technologies operated simultaneously. It is likely that the majority of iron required for steel production was produced on the same site. The only exceptions may be the large production sites at Konasamudram (**PM65** and **PM67**) and Konapur (**PM60** and **PM62**) where the smelting remains are significantly less prominent than the crucible remains. In this case, it is possible that iron was imported from surrounding production sites. Indeed, Voysey who witnessed crucible steel production at Konasamudram (see chapter 2.2) states that iron was imported from the locality to be used in the process (Voysey 1832).

The waste material at several sites also appears to have been segregated. Crucible steel or iron smelting remains were more prominent in different parts of these sites, suggesting that although both technologies probably operated simultaneously, they were segregated on site. As a whole, the dominance of iron smelting sites in the region and the relatively large size of the deposits in comparison to crucible steel sites, suggests that iron production was greater than the feedstock needs of crucible steel production. It can be concluded therefore, that iron was also produced for other purposes, most likely for local use (tools) or even trade.

The major characteristics of each site group were described and several trends were observed. The majority of sites were large with significant amounts of waste material but most were also disturbed in some way, usually due to the expansion of settlements, roads and agriculture. The best preserved sites were unsurprisingly found in more remote areas such as forests and unused bare scrubland, whereas the most disturbed were often located in villages or agricultural land. It is also significant that the majority of smelting sites are found either on the edges of villages or further away in the now dominant agricultural landscape. Several reasons for this can be proposed, such as the possibility that the workers needed more space than was afforded in settlements, or perhaps the groups involved were of a lower social status and marginalised. The comparison of location setting by metallurgical site group also revealed trends. It is evident that sites where crucible steel production predominates are more likely to be located within and around settlements than smelting sites. It is likely that crucible steel production, especially on a large scale, was centralised, requiring a larger workforce. Production centres within or close to settlements would also have had easier contact routes, facilitating commerce, trade and probably economic and administrative control.

The most relevant site characteristic proved to be the location settings which showed the most variation between site types. In contrast, size, deposit depth and preservation status showed little correlation with site type. These appear to be mostly influenced by site setting and the degree of human interference. It is important to point out here, that the metallurgical site types identified and assessed in this chapter were based on the broad identification of the two dominant technologies, iron smelting and crucible steel. The large quantity of archaeometallurgical material collected from these sites has the potential to reveal much more about the technologies once in operation in the region. The in-depth visual analysis of the metallurgical waste will enable the identification of the technologies and provide further comparative data to assess site and technological trends beyond the broad crucible steel and smelting groupings. This will be the subject of the following chapters (6 and 7). where material typologies will be defined and then used to identify specific technological types.

6 Macro-morphology and Typology

The analysis of the archaeometallurgical waste material from the sites surveyed during the Pioneering Metallurgy Project forms the main focus of this study. It is particularly important since no research to date has undertaken a detailed analysis of the material from this region and tackled the reconstruction of technologies employed. As outlined in chapter 2.3, past studies have concentrated on the analysis of crucible fragments from one site, Konasamudram (Lowe 1989a; 1989b; 1991; Balasubramaniam *et al* 2007). The result is that little is known about other crucible production sites. In addition, no work has dealt with the recording of associated local technologies such as the smelting of iron, the feedstock for crucible steel production. This is significant because iron smelting remains represent the majority of the archaeometallurgical evidence in this region (chapter 5). These gaps in previous research are what will be addressed here.

Material samples were collected from almost all metallurgical sites surveyed, the sampling strategy and methods are described in chapter 4.2.1. All the material was then visually analysed as outlined in chapter 4.2.2. This included recording the minimum and maximum size ranges, weight and descriptive attributes such as shape, colour, texture, porosity and what type of material they were made from. The focus of this chapter is to present the macro-morphological observations of the assemblage as a whole, including quantification and presenting the final typologies defined for each waste material category. It is important to mention that, due to the quantity of data collected, it cannot be presented here in its entirety. Only the most important morphological attributes of each material type will be outlined. More detailed descriptions of material types and quantitative data pertaining to individual locations are in appendix C. The assessment of data trends and identification of the metallurgical technologies will be the focus of the following chapter.

6.1 Assemblage Quantification

The whole collected assemblage comprised 1610.282kg (or 1.61 tonnes) of technological waste. This material was collected from 189 different locations now resolved as 114 sites. Refer to appendix B for full data tables with material weights by site. It is important to reiterate here that the assemblage is not quantitatively representative of the materials present at these sites, but is qualitatively representative of the materials observed. The majority of the material sampled was taken from the 101 metallurgical sites recorded during fieldwork (see chapter 5.1.4). Indeed, all metallurgical sites except three (PM61, PM68 and PM126) were sampled. Some technological waste was also collected from several historical sites where material was secondary or heavily disturbed (PM4, PM20, PM29, PM89, PM114, PM121 and PM139) and iron ore samples were collected from many of the geological sites.

The material was visually analysed and sorted into ten major types. These included tap slag, furnace slag, smithing slag, furnace wall, tuyeres, crucibles, glassy slag, ore, geological and iron. The weight percent proportions of each material type in the assemblage is illustrated in figure 6.1. The majority of the material collected were slags which constitute around 67%, with tap and furnace slags each accounting for around 1/3rd of the total assemblage. The next most dominant category was the furnace wall fragments, making 18% of the total weight, followed by tuyere and crucible fragments at 6% and 4% respectively. Ores and geological material accounted for approximately 2%, while both glassy slag and iron metal made up less than 1%. Although slags appear to dominate the assemblage by weight, it is not necessarily a reflection of a greater number of slag fragments than other material types. Slag tends to be heavier than refractories (furnace walls, tuyeres and crucibles). Due to time constraints and the sheer scale of the assemblage, individual fragments were not counted and the quantitative analyses of the assemblage by number of fragments collected cannot be presented here. However, as a general observation, it does appear that the assemblage is dominated by smelting slags and furnace wall remains.

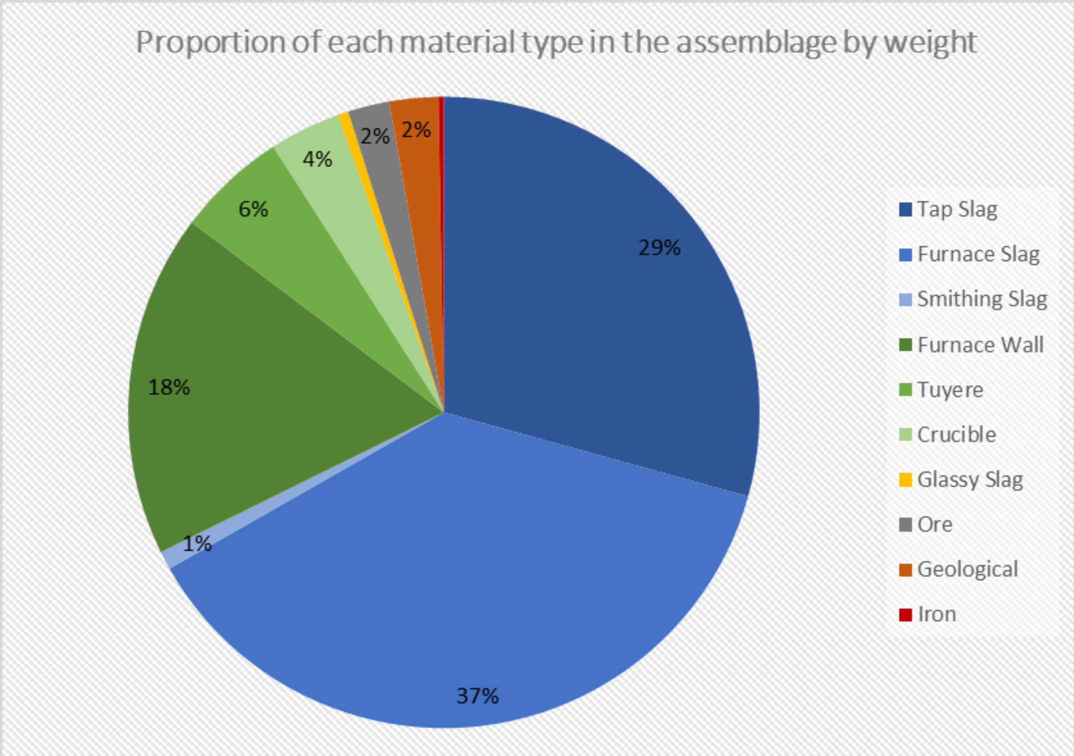


Figure 6.1 – Percentage proportion of each major material type in the assemblage by weight (1610kg).

Perhaps of more significance, since the assemblage is not quantitatively representative, is the number and proportion of sites on which each material type is found. This provides a good indication of which materials are the most common and widespread throughout the region. It also gives clues to which metallurgical technology is dominant. The number and proportion of sites on which material types were sampled is illustrated in figures 6.2 and 6.3 respectively. Tap slag, furnace slag and furnace wall fragments were the most common, all found and collected from 92-100 sites (Figure 6.2), equating to approximately 70% of sites or around 90% of metallurgical sites (Figure 6.3). Tuyeres were also very common, having been collected from 65 sites, equating to 47% of all sites or 64% of metallurgical sites. The next most common material were ores, found in 37 sites or 27% of all sites. Smithing slag, crucible, glassy slag and iron fragments were least common and only found on 27 or less sites (Figure 6.2), equating to <20% of all sites or <27% of metallurgical sites (Figure 6.3). Unsurprisingly, this suggests that iron smelting was the most widespread technology throughout the region, with its remains (primarily slags, furnace walls and tuyeres) being present on the majority of sites. This supports the observations discussed in chapter 5, that most metallurgical sites have evidence of iron smelting.

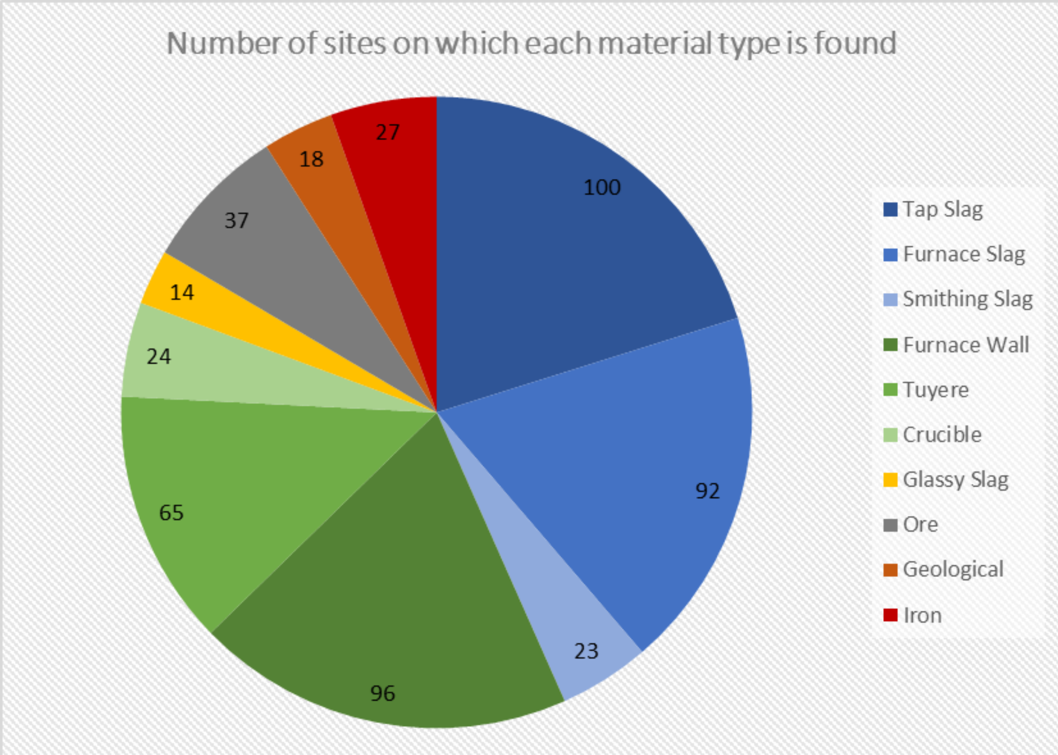


Figure 6.2 – Number of sites on which each material type is found.

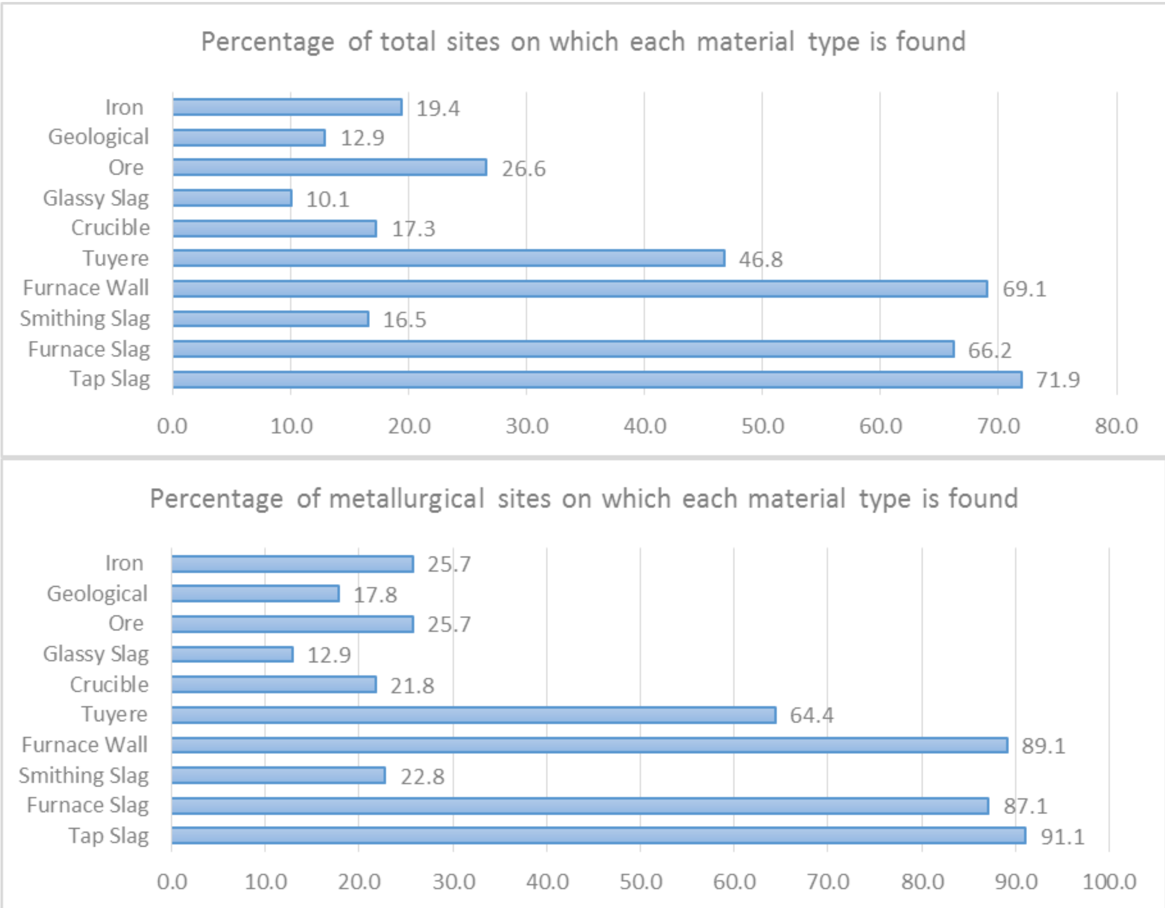


Figure 6.3 – Percentage of sites on which each material type is found. The top chart is based on the total number of sites while the bottom chart only takes into account metallurgical sites.

6.2 Typologies

In the process of recording and analysing the assemblage it became clear that the morphological characteristics of materials varied greatly, even within individual material types. Similarities and dissimilarities became increasingly apparent, and as more material was observed it was possible to group these into material sub-types based on shared morphological attributes. Sub-types of material were created for every material type and given a code, usually the initials of the main material group followed by a sequential number, for example, TS1 for tap slag type 1 or FW2 for furnace wall type 2. In cases where morphological variance were only slight, not significant enough to warrant the creation of a new type but still noticeable and relevant, the sub-types were divided again with the addition of another sequential number. For example, TS1.1 for tap slag type 1 category 1 or FW2.1 for furnace slag type 2, category 1. Due to the large quantity of material and the numerous sites and contexts on which material was found, the assemblage is complex, displaying a wide range of morphological properties. This complexity resulted in the identification and creation of 56 material sub-types across the ten major material type groups, each incorporating between two and fifteen sub-types.

This section will deal with illustrating, discussing and interpreting the major morphological differences between these material sub-types. Each sub-type will be quantified in relation to its specific material type group to show which kinds of materials are more common. Brief descriptions of each sub-type will also be presented, supported by photographs and where relevant graphs comparing them by size or weight. The scale of the assemblage and surveyed area means that it is impossible to discuss all material sub-types in relation to individual sites in detail, so only major trends will be outlined here. However, more in-depth material descriptions and a full quantification of materials found at each location, including weights, general dimensions and more detailed morphological attributes can be found in appendix C.

6.2.1 Tap Slags

Tap slags were the second most abundant material by weight (471.6kg) accounting for 29% of the entire assemblage. Most of the slag recovered was fragmentary, with few surviving whole, however, the majority had well preserved top and bottom surfaces which enabled the identification of five sub-types. The proportion in weight percentage of each sub-type as well as the number of sites on which they were found is illustrated in figure 6.4. TS1 is dominant, accounting for 59% of the total weight of tap slag with a presence in 85 sites, more than double the next most abundant sub-type. The least common are TS1.2 and TS3, making up only 5% and 3% of the total weight and present in only 16 and 15 sites respectively. The main characteristic features and size range of each tap slag sub-type as well as the sites on which they were found is given in table 6.1.

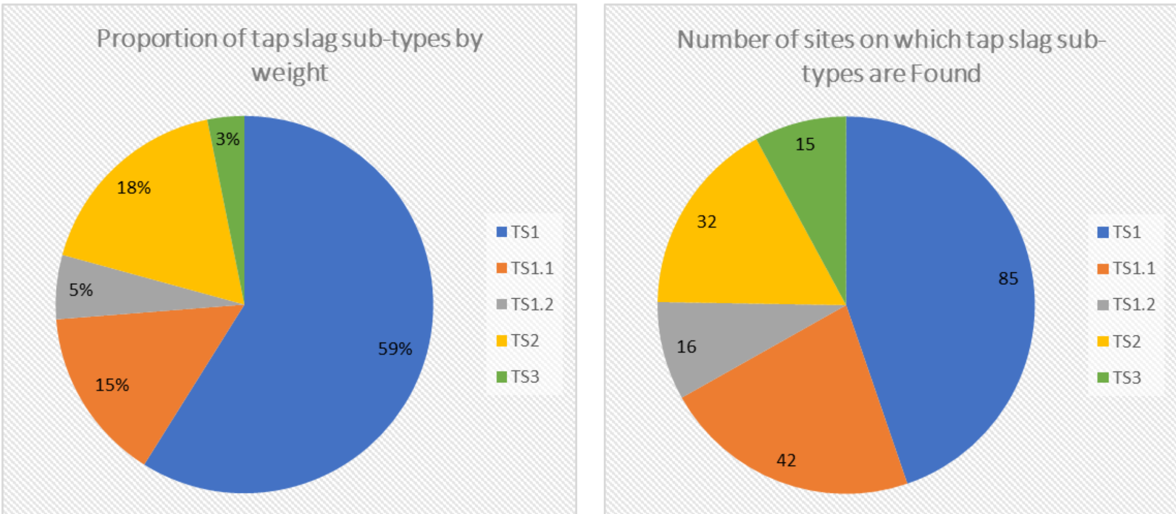


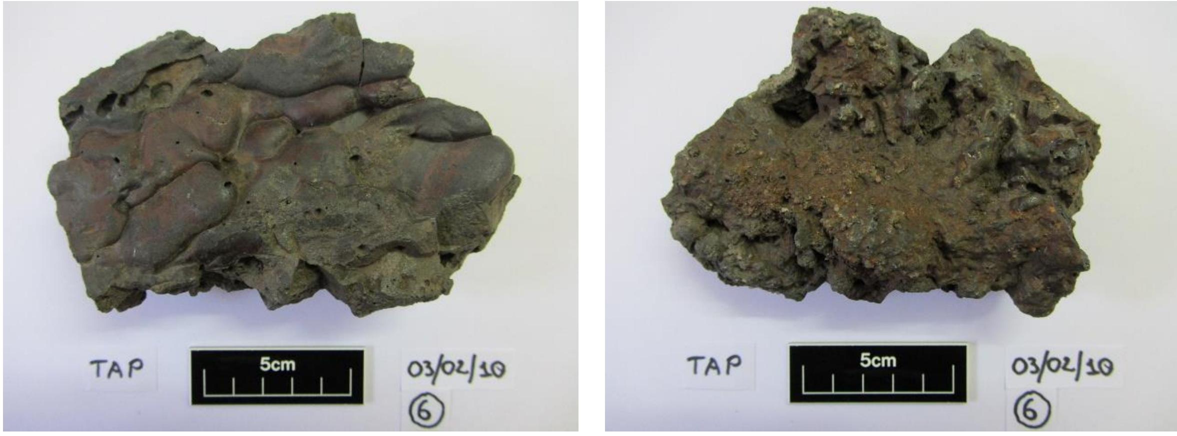
Figure 6.4 – Proportion of tap slag sub-types by weight (472kg) (left) and number of sites on which they were found (right).

Table 6.1 – Main characteristic features, size range of each tap slag sub-type and the sites on which they were found.

Type	Characteristic Features	Size Range (LxWxT)	Sites Present (PM)
TS1	Rippled smooth top surface; undulated bottom surface; dark greyish blue in colour often with varying shades of dark red/purple and brown patches; mostly solid to semi porous.	16x16x14mm to 445x264x76mm up to 104mm T	3; 4; 8; 9; 10; 11; 14; 19; 21; 22; 24; 26; 27; 30; 34; 35; 38; 42; 44; 45; 46; 47; 48; 49; 50; 51; 52; 54; 55; 58; 59; 60; 64; 65; 67; 69; 70; 72; 73; 74; 76; 77; 79; 80; 82; 83; 84; 85; 87; 88; 91; 93; 94; 96; 99; 100; 101; 102; 106; 108; 110; 112; 113; 114; 115; 116; 117; 118; 119; 120; 121; 123; 124; 125; 127; 128; 129; 130; 131; 132; 134; 135; 137; 139.
TS1.1	Mostly large solid cakes; top surfaces broken revealing more porosity below surface, crystallisation common.	32x18x27mm to 301x198x72mm up to 112mm T	14; 18; 19; 20; 22; 24; 29; 30; 34; 38; 39; 40; 42; 44; 45; 46; 48; 49; 50; 52; 54; 58; 64; 70; 76; 77; 79; 82; 84; 85; 87; 88; 89; 91; 97; 99; 100; 101; 102; 103; 106; 108; 111; 112; 117; 118; 121; 123; 125; 127; 128; 134.
TS1.2	Rough crimpled top surface; undulated bottom surface; dark greyish blue with patches of varying shades of dark red/purple, brown and orange/yellow.	46x38x23mm to 222x146x73mm up to 95mm T	14; 29; 30; 31; 39; 40; 44; 46; 72; 74; 79; 88; 91; 108; 116; 132; 134; 137.
TS2	Ropey top surface amalgamation of slag tendrils; most quite thin but some large cakes; mostly semi-porous; dark greyish blue in colour with patches dark red/purple, brown and yellowy orange.	20x18x6mm to 238x213x93mm up to 113mm T	10; 18; 24; 27; 34; 39; 40; 55; 56; 58; 60; 62; 65; 74; 79; 82; 83; 92; 95; 97; 98; 99; 100; 106; 108; 111; 112; 113; 116; 118; 124; 134.
TS3	Slag run in a purposely made channel with curved underside; sometimes covered by soil making top surface coarse sandpaper-rough.	29x28x24mm to 243x139x78mm up to 86mm T	3; 8; 26; 27; 30; 35; 46; 58; 63; 72; 74; 76; 97; 112; 129; 132.

The major morphological variants were generally associated with top surface texture and shape of the solidified runs of slag. Sub-type **TS1** can be referred to as typical tap slag, dark greyish-blue in colour, solid to semi-porous in nature with a smooth rippled top surface (most ripples 15-50mm wide) and undulated bottom surface (Figure 6.5). Sub-types TS1.1 and TS1.2 differ mostly in top surface texture. **TS1.1** slags are large, solid cakes often crystallised and shiny in section, but their top surfaces are missing, apparently broken off due to the large flattened voids that were trapped below this surface (Figure 6.5). **TS1.2** slags have rough crimpled surfaces (linear folds usually perpendicular to the flow of the slag). Small stones embedded in the surface suggest that they were covered with soil while still partially molten (Figure 6.5).

All three type 1 tap slags have similar characteristics. Their bottom surfaces display the same undulated texture with some variation to mid-rough where the slag ran over small stones, soil and ground debris. The size ranges are also similar, with small to large fragments common in all three sub-types, but on the whole TS1.1 fragments appear to be slightly thicker in nature and more solid, with few spherical/elongated voids concentrated close to the top surface. On the whole, most fragments were relatively flat (plano-plano) in profile but larger examples were plano-convex with curved undersides. This suggests that the slag pooled in small ground depressions, creating larger, thicker tap slag cakes. The slight differences between these three sub-types do not necessarily represent different technologies. It seems that they can be mostly attributed to certain actions taken by the iron smelters, such as covering the slag runs with soil, as well as post depositional processes accounting for the missing top surfaces of sub-type TS1.1.



PM42 – TS1

PM39 – TS1.1

PM134 – TS1.2

Figure 6.5 – Tap slag sub-type TS1 (top), TS1.1 (centre) and TS1.2 (bottom).

Tap slag sub-types TS2 and TS3 differ slightly from the more common TS1. All are fragmentary with fractures present on most edges. The major characteristic feature of **TS2** slags is that they are composed of an amalgamation of slag tendrils (trickles), forming cakes made up of small overlapping slag runs (Figure 6.6). These runs are smaller than the ripples noticed on the TS1 examples (most 8-20mm in width) suggesting that the slag was more viscous. The overlapping slag runs on the top surface are for the most part well-rounded and smooth, often meandering in the same direction. Their profile, visible on the broken edges, show many layers of slag where slag flows ran on top of previous flows. Unlike other sub-types, the porosity is randomly distributed throughout the thickness, often in between those individual slag runs. They also have similarities with other tap slags, being dark greyish-blue in colour, semi-porous in nature and having undulated undersides with impressions of small stones and ground debris. The undersides, however, do appear to be more uneven and rougher than most other sub-types, often with larger undulations and sharper protrusions (Figure 6.6). Most are plano-plano in profile but a few do have convex bases where they have solidified in a ground depression. Others, are very uneven suggesting they ran over ground debris.

Two large fragments from PM24 and PM27 have features of particular interest. Both have large protrusions rising from their top surfaces. These are broken at the top but are clearly the remnants of vertical slag runs, flowing into the larger mass of the cake. This suggests that these two large cakes pooled in a depression, the slag being funnelled into it from the top, or dribbled down directly from the furnace. This is supported by the fact that both have convex bases. The projection on the fragment from PM24 is located on one edge where the slag then ran out in one direction. The example from PM27 has two projections in the centre with the slag fanning out in all directions (Figure 6.6). In addition, an almost complete slag run was recovered from PM58. It is 245mm in length and is broken on one end. This flow, again made up of overlapping unidirectional slag tendrils appears to have been funnelled out of the furnace, evident from its convex underside perpendicular to the flow. The broken end is much rougher and more agitated, similar to furnace slag, suggesting that it was probably close to the furnace and smoothed out as it ran further away.

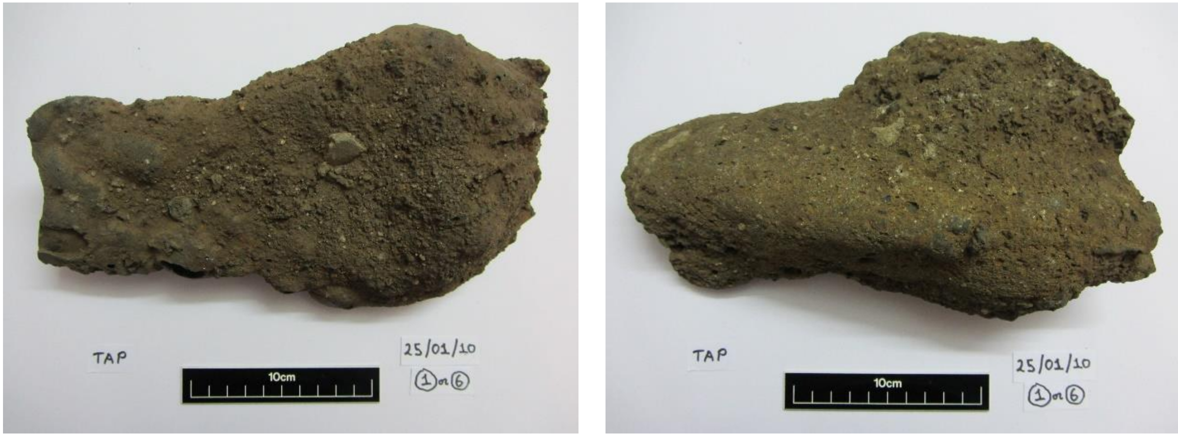
PM58 – TS2

PM27 – TS2

Figure 6.6 - Tap slag sub-type TS2. Note the top surface protrusions on the large TS2 fragment (bottom).

TS3 slags are distinct due to the fact that they all appear to have been funnelled, presumably away from the furnace (furnace drains). This is evident from their convex undersides perpendicular to the slag flow (half of a cylinder). In support, is the bottom surface texture which is dominated by gritty, soily material with many small stone and quartz inclusions (Figure 6.7). This makes most surfaces medium to coarse sandpaper-rough in texture and sometimes friable suggesting that these slags ran over loose soil. In many cases, the TS3 slags seem to be singular flows or at least well fused with no surface ripples suggesting low viscosity. The top surfaces are for the most part coarse sandpaper-rough and dark grey to dark greyish-blue in colour. Many have similar textures to their undersides with small stone and quartz inclusions suggesting that some may have been covered with soil, perhaps to protect the smelters from the emanating heat.

Most examples are broken at both ends and range in length from 29 to 243mm. These broken profiles reveal the slags to be mostly semi-porous in nature. The side edges, except for a few examples, are complete, showing well rounded surfaces. A few fragments also have one surviving well-rounded end which is presumably the end of the flow. A good example of this is shown in figure 6.7. A few examples have one very rough and agitated broken end with many charcoal impressions and in one case (from PM26) even some adhering clay. These ends must have been the start of the flow, either starting inside the furnace or at the furnace wall. In support are examples from PM26 and PM97, which are almost circular in plan at the rough end (Figure 6.7) suggesting that they may have flowed out of the furnace through a small circular hole. A few fragments are also slightly different as they are almost cylindrical in shape with one wider end. It is possible that these solidified within a small hole in the furnace purposely built to tap slag. Another possibility is that they solidified within a tuyere.



PM3 – TS3


PM26 – TS3

Figure 6.7 - Tap slag sub-type TS3. Note the rounded end of the TS3 fragment (top) and the rougher almost circular in plan end of the TS3 fragment (bottom).

6.2.2 Furnace Slags

Furnace slags were the most abundant material by weight (603.4kg) accounting for 37% of the entire assemblage. Most of the slags recovered were fragmentary but some, particularly the FS1 slags, survived almost complete. Most also had at least part of their original surfaces remaining which enabled the identification of fifteen sub-types. The proportion in weight percent of each sub-type as well as the number of sites on which they were found is illustrated in figure 6.8. FS1 is the dominant sub-type, accounting for 24% of the total weight of furnace slag with a presence on 31 sites. These are closely followed by FS1.2 and FS5, accounting for 17% and 14% of the total weight respectively. FS5 slags are also the most common, collected from 36 sites. FS1.1 and FS2.1 sub-types make up a significant proportion of the assemblage, accounting for 7% and 10% respectively. All others make up 5% or less and are present on 30 or less sites. The main characteristic features and size range of each furnace slag sub-type as well as the sites on which they were found is given in table 6.2.

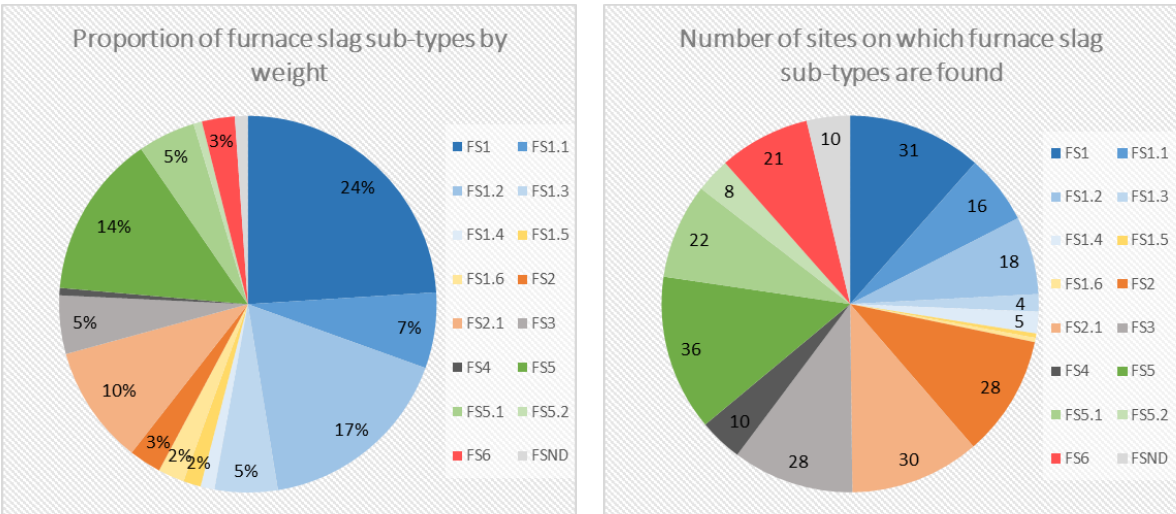


Figure 6.8 - Proportion of furnace slag sub-types by weight (603kg) (left) and number of sites on which they were found (right).

Table 6.2 - Main characteristic features, size range of each furnace slag sub-type and the sites on which they were found.

Type	Characteristic Features	Size Range (LxWxT)	Sites Present (PM)
FS1	Curved (convex) base, large plano-convex cakes, circular in plan, approximately 300mm in diameter, mostly solid to semi-porous.	60x58x52mm to 339x285x105mm up to 105mm T	9; 18; 19; 21; 22; 38; 42; 46; 49; 54; 55; 56; 63; 64; 69; 77; 79; 80; 83; 87; 91; 93; 95; 97; 112; 116; 125; 127; 128; 132; 139.
FS1.1	Mostly agitated bulbous top surfaces, curved (convex) bases often with a crust, porous to very porous (honeycomb) in nature.	84x47x39mm to 323x292x130mm up to 130mm T	40; 54; 55; 58; 74; 77; 84; 85; 108; 110; 111; 112; 128; 131; 132; 134.
FS1.2	Plano-convex cakes, circular plan, small diameter (200-250mm).	73x66x72mm to 250x250x150mm	8; 22; 26; 27; 34; 46; 51; 55; 56; 58; 60; 65; 69; 73; 74; 75; 100; 128; 129.
FS1.3	Concavo-convex profile, circular plan, mid-rough top surface with few protrusions, base dominated by adhering reduced clay.	165x144x54mm to 287x255x80mm	28; 31; 56; 119.
FS1.4	Small plano-convex cakes, circular in plan, <200mm diameter, rough top surface, curved and rough/sandpaper-rough base.	85x67x57mm to 182x167x59mm	55; 58; 79; 100; 130.
FS1.5	Very small plano-convex cakes, most complete, clear slag layering.	115x100x75mm to 143x113x63mm	35.
FS1.6	Large plano-convex cake, bucket shaped.	211x211x210mm	128.
FS2	All broken edges, dominated by charcoal impressions and voids, very rough surfaces, porous to very porous.	33mm max L to 196x125x73mm	18; 24; 31; 34; 39; 46; 47; 48; 51; 54; 58; 63; 65; 69; 72; 74; 85; 89; 91; 92; 99; 102; 106; 120; 125.
FS2.1	Amorphous more complete lumps, tendril flow slag, dominated by charcoal voids and impressions.	<10mm max L to 206x128x96mm	3; 10; 18; 34; 39; 42; 44; 54; 55; 56; 58; 60; 65; 83; 85; 91; 93; 94; 99; 100; 104; 108; 111; 118; 125; 127; 128; 129; 132; 134.
FS3	Small solid to semi-porous amorphous lumps, almost complete.	<40mm max L to 199x159x118mm	8; 9; 11; 20; 24; 34; 38; 46; 54; 58; 74; 75; 79; 87; 89; 90; 91; 99; 100; 101; 102; 108; 113; 117; 119; 121; 125; 129.
FS4	Amorphous small lumps, rough to very rough uneven surfaces.	30mm max L to 111x95x43mm	26; 27; 46; 54; 64; 74; 80; 88; 127; 130.
FS5	Shaped convex undulated base (plano-convex), medium to rough top surfaces with no to few large protrusions, reasonably thin profiles/thicknesses.	49x35x26mm to 316x330x103mm	3; 8; 9; 10; 18; 21; 28; 30; 39; 40; 42; 45; 46; 49; 51; 52; 55; 58; 60; 63; 73; 74; 75; 83; 84; 85; 91; 92; 93; 95; 99; 100; 108; 112; 118; 130; 134.
FS5.1	Curved (convex) bottom surfaces, mostly broken, varying top surfaces and porosity.	57x51x41mm to 203x152x106mm	20; 24; 26; 27; 28; 44; 45; 48; 55; 58; 74; 82; 88; 90; 104; 108; 113; 115; 118; 124; 130; 134.
FS5.2	Small cylindrical shaped slag, channelled with one tapering end.	72x14x20mm to 198x153x91mm	24; 35; 54; 58; 64; 76; 110; 127.
FS6	Amorphous, mostly broken edges, rough to very rough textured and very porous (honeycomb) in nature.	<49mm max L to 210x123x151mm	14; 19; 30; 55; 63; 74; 79; 80; 88; 91; 94; 101; 102; 110; 111; 112; 113; 118; 119; 132; 134.
ND	Non-diagnostic, small broken fragments.	<139mm max L	21; 31; 46; 60; 74; 76; 98; 100; 102; 103.

Sub-type 1 furnace slags were some of the largest and most dense single slag fragments recovered and unsurprisingly their combined weight makes up approximately 58% of the furnace slag assemblage. The majority were broken but in most cases enough of the original surfaces and edges remained to estimate original size. All sub-types of FS1 share some physical attributes. They are all circular or oval in plan and plano-convex or concavo-convex in profile, with a relatively flat top and rounded bottom surface. This characteristic shape as well as their well-defined edges and surfaces suggests that they solidified in a contained environment, most likely at the bottom of a furnace. Hence, they are good indicators of furnace internal diameters. However, there are considerable morphological variations, especially in size, shape and surface texture allowing seven sub-types (FS1 to FS1.6) to be identified. This suggests significant variation in furnace size and perhaps smelting technology. The diameter and thickness ranges of the best preserved examples in each sub-type is presented in figure 6.9, providing a clearer picture of the varying sizes of all plano-convex slag cake sub-types.

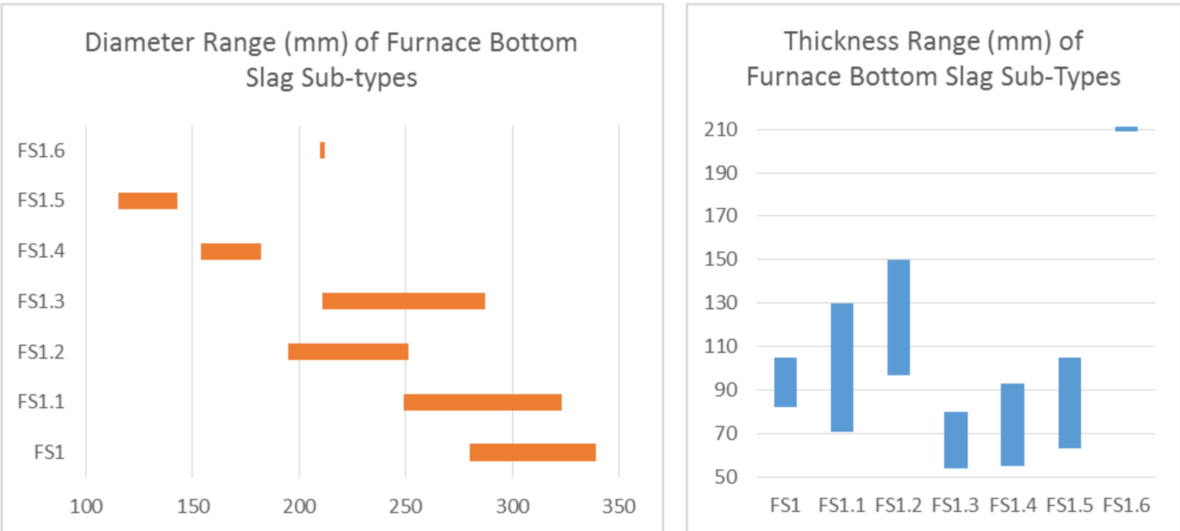


Figure 6.9 – Diameter (left) and thickness (right) range of the better preserved examples in each furnace bottom sub-type.

Sub-types **FS1** and **FS1.1** are similar in shape and size with a diameter averaging around 300mm and a thickness around 90-100mm. FS1.1 cakes vary more in size with diameters as low as 249mm and thicknesses between 71 and 130mm. The majority of the slags are dark greyish-blue in colour with a few displaying shiny crystallisation on fresh fractures. The top surfaces of FS1 and FS1.1 cakes are rough to very rough in texture with globular (sometime broken) projections rising no more than a few centimetres above the surface. These are coarse sandpaper-rough and most examples have large charcoal impressions (up to 50mm) nested between the bulbous projections (Figure 6.10). Naturally, there is some variation in texture with examples being slightly smoother with flatter almost rippled/crimpled top surfaces and smaller charcoal impressions (<22mm).

Their undersides are all very similar, evenly convex with no to few protrusions of material. The majority are medium to coarse sandpaper-rough in texture dominated by small stone and charcoal impressions (Figure 6.10). These charcoal impressions are typically <6mm (up to 12mm) and cover the entirety of the undersides suggesting that the bottom of the furnace was intentionally lined with charcoal fines. This is a common practice to prevent the slag and iron bloom from sticking to the furnace base, facilitating removal and extending the life of the furnace structure (Keen pers. comm., 2009). It also helps insulate the furnace bottom to keep the slag molten and enable it to be tapped when required (Keen 2013, 103). Similar processes were described by both Keen (2013, 101) and Elwin (1942, 108) in their accounts of smelting by the Agaria people of Madhya Pradesh. The undersides also vary in colouration with large dark reddish-orangey-brown patches. Where sub-types FS1 and FS1.1 differ is in their porosity. Both types have relatively solid surfaces with few voids but since the majority are broken, fractures reveal their internal profile. The FS1 slags are semi-porous with a random distribution of globular voids (most <30mm) throughout their thickness although larger voids do have a tendency to concentrate closer to the top surface. FS1.1 slags are all porous to very porous, dominated by small spherical or globular voids (most <12mm) giving a honeycomb-like texture. This is particularly noticeable on their undersides which constitute of a thin solid crust (3-10mm thick) often partially chipped off revealing the porosity of the main body (Figure 6.10).

A few FS1 fragments recovered from PM46, PM49, PM79, PM93 and PM95, although similar in shape and texture, differ slightly by being much thinner (<70mm) and the fragment from PM79 appears to have an internal diameter in excess of 400mm.

Figure 6.10 - Furnace slag sub-type FS1 (top) and FS1.1 (bottom). Note the thin, solid crust on the underside of the FS1.1 fragment, revealing honeycomb porosity underneath (bottom).

FS1.2, FS1.3 and FS.1.4 slags vary greatly in size but all share similar characteristics to FS1 and FS1.1 slags by having well defined convex undersides, being dark grey (greyish-blue) in colour and generally rough in texture. The **FS1.2** cakes have small to medium diameters (195-251mm) and are on the whole much thicker than any other plano-convex sub-type, between 97 and 150mm. Many examples are complete or almost complete with only few showing broken edges. Their top surface textures vary considerably but most are similar to FS1 and FS1.1 slags with bulbous or sharp projections and charcoal impressions up to 58mm (most <25mm). Some examples have rough, agitated ripples or crimpled surfaces. The undersides also vary greatly with many being dominated by small stones or grit. Others, are more uneven with a mixture of stone undulations and charcoal impressions (most <10mm) giving a coarse sandpaper texture (Figure 6.11).

One example, from PM55, also has an underside covered in dark grey vitrified clay. Several FS1.2 cakes from PM27, PM56 and PM129 also have interesting features in the form of elongated (linear) projections on their undersides. This suggests that the furnace bases may have been intentionally prodded, perhaps to release blockages, enabling the tapping of slag. In addition, two fragments (from PM8 and PM73) appear to have tool marks on their top surfaces. These are large linear impressions up to 50mm wide which appear to have smeared the slag surfaces (Figure 6.11).

PM22 – FS1.2

PM73 – FS1.2

Figure 6.11 - Furnace slag sub-type FS1.2. Note the large elongated impressions on the top surface of the fragment on the bottom.

FS1.3 slags are much less abundant and occur on very few sites. They have similar diameters to FS1 and FS1.1 slags (around 211-287mm) but are on the whole much thinner (54-80mm). They also differ by being concavo-convex in profile with gently sloping shallow depressions on their top surfaces (Figure 6.12). These surfaces also tend to be more even, medium rough with smaller protrusions of material and charcoal impressions (most <12mm). The convex undersides are mostly covered in a layer of dark grey reduced coarse clay between 5 and 18mm thick (Figure 6.12). In many cases, part of this clay has chipped off with no original clay surfaces remaining. The clay is well fused to the slag cakes with heavily vitrified contact areas suggesting they fused when the slag was hot and molten. It suggests that the base of these furnaces were lined with clay. The fractured edges reveal most cakes to be low to semi-porous with few random spherical and globular voids.

FS1.4 slags are also few in number. They are closely related in morphology to the FS1, FS1.1 and FS1.2 slags, with similar top and bottom surface texture variations. What differentiates them is their small diameter, between 154-182mm, suggesting that they were no bigger than 200mm in diameter (Figure 6.12).

PM28 – FS1.3

PM55 – FS1.4

Figure 6.12 - Furnace slag sub-type FS1.3 (top) and FS1.4 (bottom). Note the clay covered underside and convex top of the FS1.3 fragment and the small size of the FS1.4 fragment.

Of particular interest are two distinct plano-convex furnace slag cake sub-types, FS1.5 and FS1.6. Their major defining features are their size and shape which differ greatly from all other furnace slags. It is also important to note that they were only found at single locations, FS1.5 at PM35 and FS1.6 at PM128.

The majority of the **FS1.5** cakes recovered were largely complete but a few had broken sections. They are the smallest plano-convex cakes in the assemblage with a maximum diameter of 143mm and maximum thickness of 105mm, although those that were wider tended to be thinner and *vice versa*. Their shapes are well defined with solid surfaces, roughly circular plans and steep convex undersides (Figure 6.13). Those with broken edges reveal semi-porous textures. The top surfaces varied in texture, from coarse sandpaper-rough with small bulbous projections to rougher more agitated sharp projections. In some cases, there was a slight depression on the top surface making them almost concavo-convex in profile. No charcoal impressions were noticeable but some of the more angular depressions may have been shaped by charcoal. This suggests a greater surface tension than other slag cakes.

They consist of amalgamations of small overlapping slag runs. This is clearly seen on the undersides which show meandering horizontal solidification fronts (perpendicular to the top surface - Figure 6.13). It suggests that the slag was relatively viscous in nature and that previous slag flows partially solidified before another flow covered it. The undersides are medium to coarse sandpaper-rough and dominated by very small undulations. These are mostly from small stones/quartz but there are also many small organic (charcoal or plant material) impressions, 2-3mm wide and up to 30mm long. Refer to chapter 7.1.7 for more discussion on these slag cakes.

Only one cake of sub-type **FS1.6** was recorded and although it is much larger than the FS1.5 slags, it shares many morphological similarities. Its shape and size are unique within the assemblage. It is bucket-shaped, 211mm in diameter and is the thickest slag recorded at 210mm (Figure 6.13). Its top surface is relatively flat, very rough with small to medium sharp projections of material intersected by angular charcoal impressions. The surfaces are relatively solid but the broken projections do reveal some spherical and globular porosity. The sides are very steep and taper slightly towards the base where the slag rounds off in a well-defined convex shape (Figure 6.13). Similar to the FS1.5 cakes, the sides and base show that it consists of an amalgamation of small slag runnels, approximately 10-20mm in width. These overlap horizontally, perpendicular to the top surface (Figure 6.13). On one side, there are remains of adhering mid to dark grey reduced coarse clay suggesting that the slag was moulded within the furnace and was surrounded by clay walls. The majority of the clay has chipped off revealing the slag layers with have a smooth to medium sandpaper-rough undulated texture. No clay was present on the underside but small stone impressions were dominant along with elongated organic impressions, similar to those on the FS1.5 slags.

PM35 – FS1.5

PM128 – FS1.6

Figure 6.13 - Furnace slag sub-type FS1.5 (top) and FS1.6 (bottom). Note the accumulation of small individual runs of slag as well as the small size of the FS1.5 cake and the bucket shape of the FS1.6 cake.

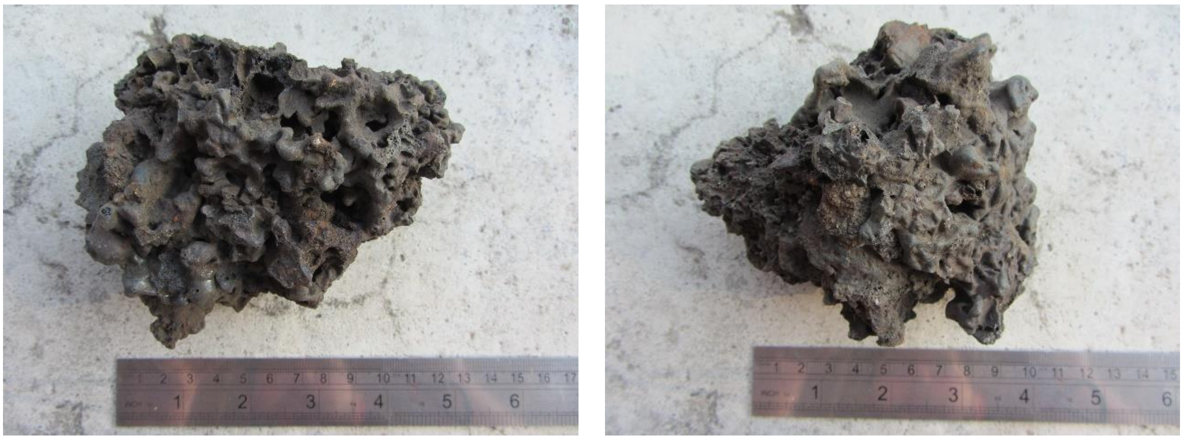
The remaining furnace slag sub-types are, for the most part, amorphous broken fragments of slag that solidified within the furnace, varying greatly in size, texture and porosity.

Some of the most common sub-types are FS2 and FS2.1 slags. Both share similar morphological characteristics. They are dark grey or dark greyish-blue in colour with patches varying in shades of dark brown, dark red and dark orange. They are amorphous in shape, porous to very porous in nature and light in density. **FS2** slags are fragmentary with few original surfaces remaining. They range in maximum size from 33mm to 196mm and are characterised by their general broken nature. The surfaces are dominated by very rough, sharp (mostly broken) medium protrusions of material, intersected by large angular charcoal voids/impressions up to 75mm but mostly <30mm in size (Figure 6.14). In some cases, remains of charcoal still adhere to the inside edges of these voids. Some small parts of the slags appear unbroken and reveal, either rounded tendril-like, or sharp and angular projections. For the most part however, these projections are broken, revealing abundant very small (<10mm) spherical and globular voids (Figure 6.14).

FS2.1 slags are very similar but differ by being complete or almost complete with few fractures. They range in size from <10mm to 206mm in maximum length and have medium to rough surfaces. They are dominated by small to medium rounded protrusions of material with large angular charcoal voids and impressions up to 45mm, nested in between (Figure 6.14). There is some variation with examples having more rounded bulbous projections while others are sharper and rougher in texture. These surfaces are similar to the more complete surfaces of the FS2 slags and similar spherical porosity is seen where the projections have been broken. It is likely that both FS2 and FS2.1 slags represent the agglomeration of molten slag that solidified around the charcoal charge.

A few fragments from both sub-types also have flattened or curved (convex) sides suggesting that they may have solidified against a hard surface, furnace wall or base. In support, are few examples which have medium to coarse reduced clay still adhering to one side. Another distinct example of FS2.1 sub-type has a large tuyere nozzle fragment stuck on one side (Figure 6.14). Unfortunately due to the poor preservation, this tuyere is not diagnostic but for more detailed descriptions, see appendix C.2.

PM18 – FS2



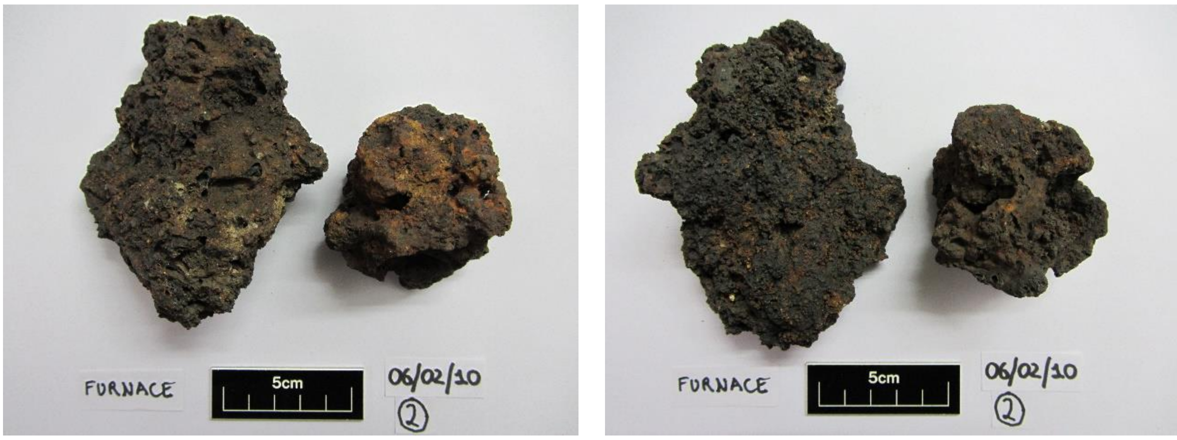
PM39 – FS2.1

PM128 – FS2.1

Figure 6.14 - Furnace slag sub-type FS2 (top) and FS2.1 (centre and bottom). Note the rough broken surfaces of the FS2 slag (top), the well-rounded projections on the FS2.1 slags and the adhering tuyere fragment (bottom).

FS3 and FS4 sub-types differ from those discussed above. Both types are amorphous and similar in colour, dark grey to dark greyish blue with patches varying in shades of dark brown, red, purple, yellow and orange. They are generally small in size (most <100mm) and complete or almost complete with few fractures. The surfaces of the **FS3** slags tend to be quite homogenous, medium coarse with small protrusions of material varying in sharpness (Figure 6.15). Some of the coloured patches are gritty in texture making these areas coarse sandpaper-rough. The slags themselves are solid to semi-porous with few random spherical or globular voids <10mm in size (Figure 6.15). Most examples also have shallow charcoal impressions (<33mm). **FS4** slags differ due to their more uneven rough to very rough surface texture. They are more angular in appearance, dominated by small to medium sharp projections and charcoal impressions (<25mm) (Figure 6.15). In addition, they are covered in very small sharp projections giving a coarse sandpaper texture (Figure 6.15). The surfaces appear relatively solid but the fractures reveal greater porosity within the slag pieces with many random spherical and globular voids <10mm in size. A few examples of both types, have one flattened side suggesting that they may have solidified against a hard surface, furnace wall or base.

PM87 – FS3



PM54 – FS4

Figure 6.15 - Furnace slag sub-type FS3 (top) and FS4 (bottom). Note the rougher surfaces of the FS4 slag (bottom).

All furnace sub-type 5 slags (FS5, FS5.1 and FS5.2) have been shaped by making contact with a hard surface, most likely the furnace walls or base. All are dark grey or dark-greyish blue in colour with patches varying in shades of dark brown, red, purple, yellow and orange. **FS5** slags are the most widely distributed, occuring on most sites. The majority are broken on all sides but all have surviving top and bottom surfaces. They vary considerably in size from 49mm to 316mm maximum length and are typically flat or concave on one side (top) and convex on the other (bottom). The majority of the top surfaces are coarse sandpaper textured with very small sharp protrusions of material but there are also larger (small to medium) protrusions giving them an overall mid to rough texture (Figure 6.16). There is some variation, with fragments displaying larger and sharper protrusions. The majority also have angular charcoal impressions, <40mm in size. The undersides are all flattened or slightly convex (on one plane). The majority have small uneven undulations and are low to mid-rough in texture with no major protrusions (Figure 6.16). It is likely that these slag fragments solidified against the curved inner wall of the furnace, evident by the reduced clay adhering to some examples. In parts, the clay has chipped off revealing a similar surface texture to the other examples in this slag sub-type. Most are semi-porous with random spherical and globular voids up to 18mm but a few are more porous. Several fragments have also taken distinctive curved shapes, moulded by the furnace wall. For more detailed descriptions, see appendix C.2.

FS5.1 slags were also shaped by the furnace wall with one curved (convex) side, however, most are amorphous in shape and vary greatly in surface texture and porosity. The majority are broken fragments, probably parts of larger slag consolidations that made contact with the furnace wall or base. They vary in size from 57mm to 203mm in maximum length and the majority have mid to rough surface textures with sharp, small to medium, protrusions of material (Figure 6.16). There is considerable variation with examples being rougher and more agitated. Their undersides are convex (on one plane) and a little rougher and grittier than the FS5 slags (Figure 6.16). Some examples also have reduced clay adhering to this surface, with significant vitrification on the contact areas, suggesting that the slag made contact with the clay lining while still hot and molten.

18/02/10 (4) FS5

05/02/10 (2) FS5.1

Figure 6.16 - Furnace slag sub-type FS5 (top) and FS5.1 (bottom). Note the more amorphous shape of the FS5.1 fragment (bottom).

FS5.2 slags deserve special mention. They are closely related to the TS3 slags discussed above. However, they are rougher in texture than the latter and appear to have solidified enclosed in cylinder shaped spaces, constricted on all sides. All are cylindrical in shape, circular or oval in cross section and taper towards one end (Figure 6.17). They vary in size from 72mm to 198mm in maximum length but all have at least one broken end, suggesting that they were longer than their current state. All surfaces are very similar with no evident orientation. They are coarse sandpaper textured, dominated by very small sharp protrusions of material, giving an almost pitted appearance (Figure 6.17). In some cases the protrusions are thin and flaky with parts chipped off revealing some small spherical and globular porosity underneath. The majority also have a few small quartz inclusions adhering to the surfaces. Broken edges reveal solid to semi-porous textures with few, randomly spread spherical voids. Of particular interest is the largest fragment which has a fan or bowl-shaped end (Figure 6.17). It appears to be part of the internal furnace slag cake. This suggests that

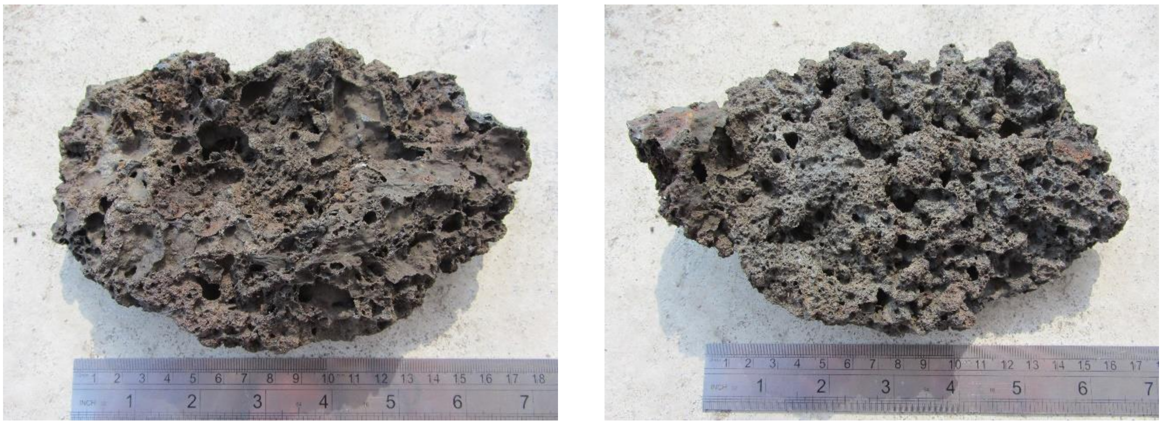
FS5.2 slags probably relate to slag tapping, whereby a small hole was made into the furnace base to allow molten slag to run out. These examples are the parts which eventually plugged these holes. It is also possible that they solidified inside tuyeres. Their tapering shapes are similar to the internal diameters of tuyere type 2 (T2 – described below). Whether or not this was intentional and old tuyeres were re-used to facilitate tapping is not yet clear. In any case they are related to the draining of slag from the furnace, FS5.2 being the start of the flow, within or close to the furnace, and TS3 slags are the continuation of this flow outside the furnace.

PM58 – FS5.2

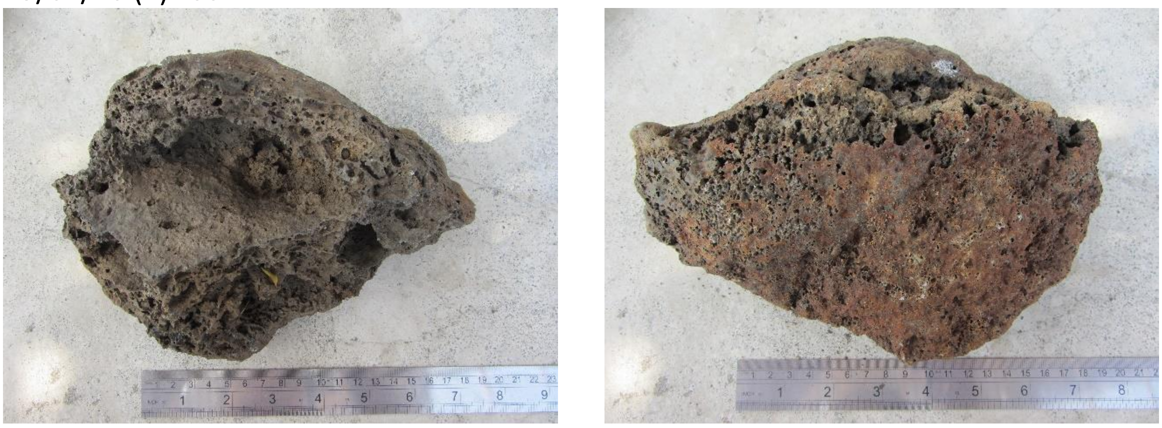
PM76 – FS5.2

Figure 6.17 - Furnace slag sub-type FS5.2. Note the fan-shaped end of the top fragment.

The last furnace slag sub-type is **FS6**. All are fragmentary, dominated by broken surfaces and amorphous in shape. They are the same dark grey to dark greyish-blue colour as other furnace slags with similar coloured patches. They range in size from <49mm to 210mm in maximum length and differ from the other slags by being very porous and light. Broken surfaces reveal dominant spherical and globular voids up to 15mm giving the slags a honeycomb texture (Figure 6.18). In many cases, these voids are interconnected forming larger void networks. The broken edges and protrusions are sharp and angular making the surfaces very rough to the touch (Figure 6.18). Very few examples have parts of their original surfaces remaining. In these areas, the slag consists of a thin crust (<1mm), coarse sandpaper in texture covering the porous insides of the slags (Figure 6.18). A few angular shallow charcoal impressions are noticeable on these original surfaces but are not present within the slag fragments themselves. Very few examples also have one shaped, rounded edge suggesting that some of these may have solidified against the furnace walls.



15/02/10 (2) FS6

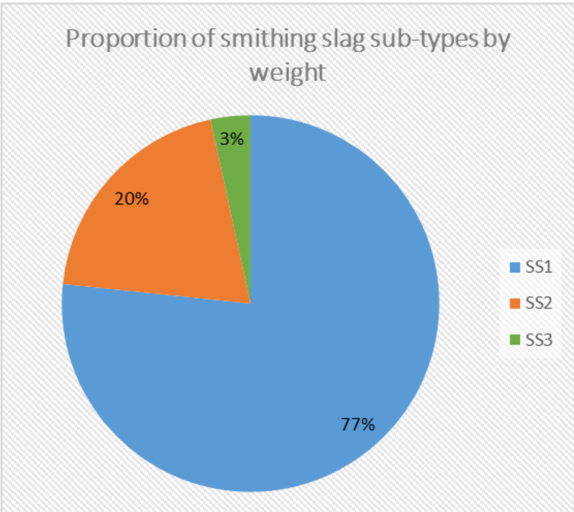


09/02/10 (6) FS6

Figure 6.18 - Furnace slag sub-type FS6. Note their very porous honeycomb-like nature and the remnants of the original surfaces in the form of a thin crust (bottom).

6.2.3 Smithing Slags

Comparatively few smithing slags in relation to smelting slags were found. A total of 15.2kg were collected accounting for approximately 1% of the entire assemblage. The majority of the smithing slag recovered was complete or almost complete enabling the identification of three sub-types. The proportion of each sub-type as well as the number of sites on which they were found is illustrated in figure 6.19. SS1 is the dominant sub-type, accounting for 77% of the total weight of smithing slags, while sub-types SS2 and SS3 contribute 20% and 3% respectively. In terms of occurrence, they are much more even, with SS1 slags found on 13 sites while SS2 and SS3 were found on 11 and 7 sites respectively. The main characteristic features and size range of each smithing slag sub-type and the sites on which they were found is given in table 6.3.



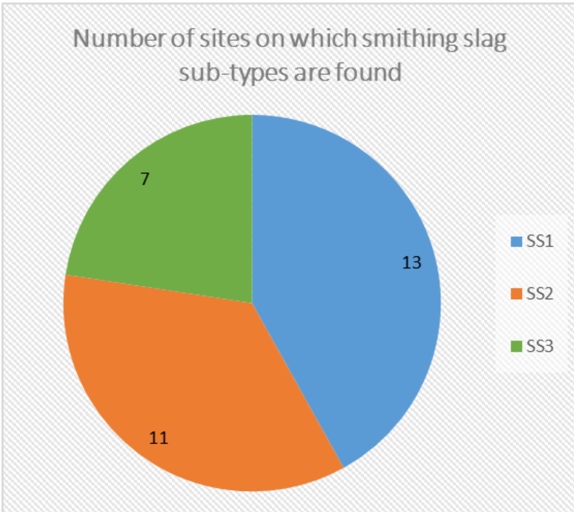


Figure 6.19 - Proportion of smithing slag sub-types by weight (15kg) (left) and number of sites on which they were found (right).

Table 6.3 - Main characteristic features, size range of each smithing slag sub-type and the sites on which they were found.

Type	Characteristic Features	Size Range (LxWxT)	Sites Present (PM)
SS1	Small plano-convex or concavo-convex cakes; circular or oval in plan; molten top surface.	60x60x27mm to 186x135x52mm up to 87mm T	35; 38; 42; 46; 50; 62; 75; 87; 90; 101; 104; 119; 134.
SS2	Small amorphous lumps (some broken), orangey-brown colour, most magnetic.	36mm to 87mm max L but most <60mm	30; 35; 58; 74; 75; 87; 101; 102; 104; 117; 120.
SS3	Thin, flat on one side and slaggy or more agitated on the other (smithing flats).	22mm max L to 70x46x13mm up to 17mm T	35; 46; 49; 55; 56; 74; 93.

SS1 slags were the most common and diagnostic smithing slag sub-type. They mostly consist of complete or almost complete small plano-convex or concavo-convex cakes, undoubtedly formed in the bases of smithing hearths. They vary in diameter from 60mm to 186mm and in thickness from 27mm to 87mm but the majority are less than 117mm in diameter and 55mm in thickness. They are dark grey to dark greyish-blue in colour, with most dominated by dark brownish-red and orangey-yellowy-brown patches (Figure 6.20). These patches are often gritty, medium to coarse sandpaper-rough in texture and approximately half of them are magnetic in parts. Their top surfaces vary greatly in texture. Some are agitated with rough, small to medium protrusions while others are smoother, with more molten looking flat or concave shallow depressions (Figure 6.20). These shallow depressions are typical of slag that solidified within a smithing hearth, where the top surface was subject to a concentrated hot blast from the air inlet (Bayley *et al* 2001, 15). These depressions tend to cover half of the surface, with rougher projections of slag on the edges (Figure 6.20). Charcoal impressions are uncommon but a few have angular impressions and voids up to 23mm in size.

The convex undersides also vary in texture. The majority are rough, dominated by small to medium projections and charcoal impressions up to 30mm (most <15mm) (Figure 6.20). A few have surfaces entirely covered by very small charcoal impressions (<5mm) suggesting that the hearths were lined with compacted charcoal fines. Others have more medium rough textured undulations similar to those found at the base of tap slag (discussed above) suggesting that they solidified against a hard compacted surface (ground or clay) (Figure 6.20). Although most intact surfaces appear solid, with few voids, those that are broken show some variation in internal porosity. Most are solid to semi-porous with few random spherical, globular and irregular voids up to 30mm (most <10mm), while others show greater porosity with more void concentrations and void networks. Of particular interest, are examples from sites PM87 and PM90 which have large light to mid grey patches (Figure 6.20). These appear to be fused to the slag suggesting that some type of foreign material was added during the smithing process. This material is most probably geological (perhaps quartz, lime or sandstone) and was possibly added as an intentional flux, a well-documented process (Bayley *et al* 2001, 14; Selskiene 2007).

PM38

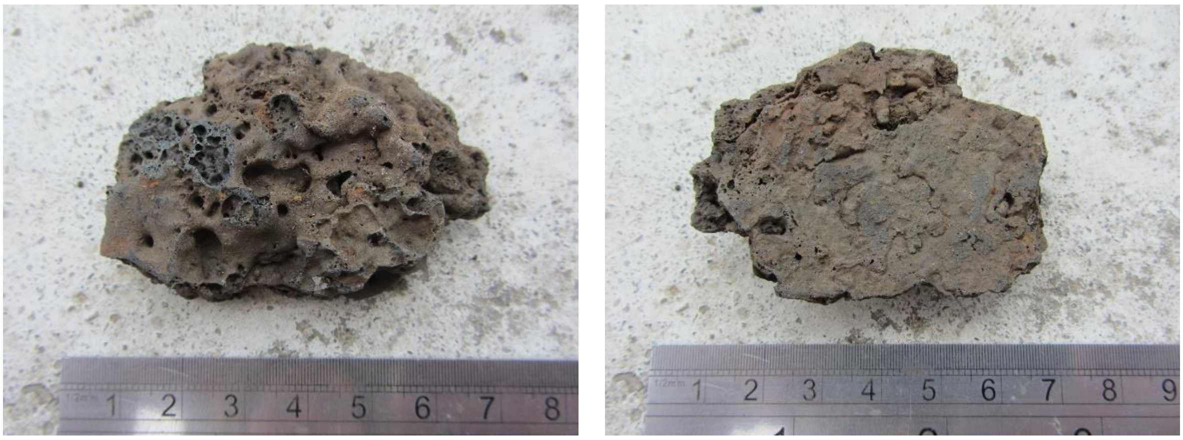
PM87

Figure 6.20 - Smithing slag sub-type SS1. Note the concave depression on the fragment from PM87 and the large greyish patch on its top surface (bottom).

Sub-type **SS2** comprises smaller, amorphous, complete or almost complete lumps of slag. These range in size from 36 to 87mm in maximum length with the majority being <60mm. They are dark grey/purple or dark greyish-blue in colour but dominated by patches varying in shades of dark-orangey-brown and brownish-red (Figure 6.21). All examples are magnetic over the majority of their surfaces suggesting high iron content. The surfaces are usually medium rough in texture with small rounded protrusions of material as well as the overall medium to coarse sandpaper texture of the coloured patches (Figure 6.21). The majority also have some shallow (faint) charcoal impressions up to 25mm in size (most <15mm). Most are solid with few small, random spherical and globular voids on their surfaces but a few are semi-porous with more numerous and slightly larger voids (<10mm).

SS3 slags are particularly interesting as they display features associated with smithing technology. They consist of small, broken fragments of thin slag, varying in maximum length from 22-70mm and 9-17mm in thickness. Their colour is similar to that of the other smithing slags and all are magnetic in parts. They are characteristic due to their distinctive shape. One side is very flat, usually smooth or sandpaper-rough to the touch with no or very few small flattened protrusions, while the reverse is more agitated with well-rounded very small to small protrusions of molten-looking slag (Figure 6.21). The agitated sides are all low to medium rough in texture but some of the fragments are slightly rougher with broken sharp protrusions. Most examples are solid to semi-porous with few random spherical or globular voids <5mm in size (Figure 6.21). These are typically referred to as ‘smithing flats’ and unlike SS1 and SS2 slags which were formed within the hearth, these were formed during the hammering process (Crew 1996). The raw iron bloom is rarely fully homogenous and contains a lot of slag which needs to be removed by smithing. As the hammer strikes the bloom, these slag layers are flattened by the blow and flake off the consolidating iron (Crew 1996). They are often identified as the product of primary smithing, whereby the raw bloom is consolidated into rough iron bars, proving that they were refined on site.

PM58 – SS2



PM93 – SS3

Figure 6.21 - Smithing slag sub-type SS2 (top) and SS3 (bottom). Note the characteristic flat side and bulbous reverse on the SS3 fragment (bottom).

6.2.4 Furnace Walls

Furnace wall fragments were the most abundant ceramic material by weight (283.1kg), accounting for 18% of the entire assemblage. All furnace walls recovered were fragmentary with none surviving whole, however, many had well preserved interior and exterior surfaces which enabled the identification of four main sub-types and four non-diagnostic sub-types. The proportion of each sub-type and the number of sites on which they were found is illustrated in figure 6.22. By weight, the dominant sub-type is FW1, accounting for 43% and present on 51 sites. All other main sub-types individually account for 8% or less and were found on 16 or less sites. The non-diagnostic sub-types are interesting as they comprise as much as 44% of the total furnace wall fragments, with FWND2 and FWND3 being dominant, making up 15% and 20% respectively. They are also very common, with FWND2 being present on 49 sites, FWND3 on 39 sites and FWND1 on 31 sites. The main characteristic features and size range of each furnace wall sub-type as well as the sites on which they were found is given in table 6.4.

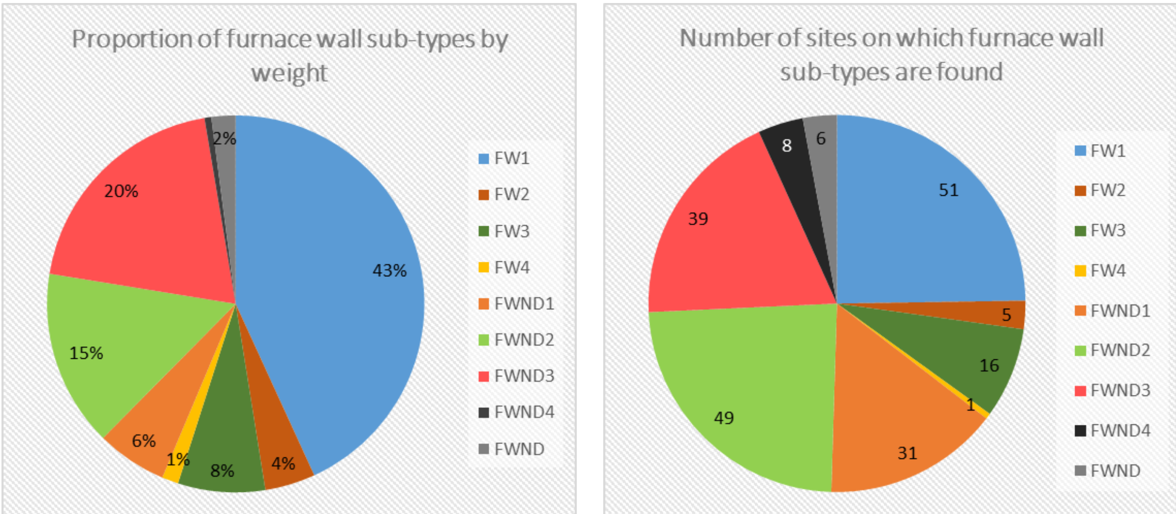


Figure 6.22 - Proportion of furnace wall sub-types by weight (283kg) (left) and number of sites on which they were found (right).

Table 6.4 - Main characteristic features, size range of each furnace wall sub-type and the sites on which they were found.

Type	Characteristic Features	Size Range	Sites Present (PM)
FW1	Flat vitrified base; light inner surface vitrification; thin walls; thicker walls at base which taper further up the furnace; fine to mid-coarse fabrics (some organic rich).	Up to 265mm L, 326mm H, 19-80mm T at base, 16-48mm T at top. ID 240-400mm, most 300-350mm	Flaring base: 45; 46; 47; 52; 56; 74; 76; 82; 99; 100; 112; 129; 131. Thick base: 14; 42; 45; 46; 52; 55; 57; 58; 73; 92; 93; 95; 132; 134. Rims: 55; 74; 92; 95. Body frags: 18; 30; 35; 42; 44; 46; 47; 49; 52; 55; 57; 58; 60; 63; 69; 72; 73; 74; 76; 77; 79; 80; 82; 83; 84; 85; 91; 92; 93; 94; 95; 99; 100; 104; 112; 113; 116; 118; 120; 124; 125; 127; 128; 129; 130;132; 134.
FW2	Coil built; thick walls; coarse to very coarse fabric.	Up to 268mm L, 222mm H, 45-90mm T	18; 57; 58; 112; 119.
FW3	Straight wall profile; vitrification on one side; reasonably thick walls; low to very coarse fabrics.	58-267mm L, 25-80mm T	3; 18; 48; 49; 52; 55; 87; 88; 89; 90; 91; 93; 116; 118; 119; 132.
FW4	Almost complete single fragment; very thick wall with flat base; many tuyere fragments used in wall construction; coarse fabric.	260mm L, 156mm H, 112mm W base, 73mm W top	113.
FW-ND1	Amorphous and fully vitrified.	<131mm L	10; 21; 22; 24; 27; 34; 42; 54; 55; 56; 63; 65; 83; 87; 88; 91; 97; 99; 100; 101; 102; 104; 106; 110; 117; 119; 121; 123; 125; 127; 133; 134.
FW-ND2	Lost the majority of their original surfaces and are either not vitrified (or the vitrification as chipped off).	66-115mm L, one frag 211mm	Not Vit: 3; 4; 42; 45; 51; 56; 70; 74; 75; 80; 88; 91; 99; 100; 108; 110; 112; 114; 120; 127; 128; 130; 132; 134. Vit: 3; 9; 14; 28; 31;34; 38; 39; 40; 45; 48; 55; 56; 58; 63; 65; 74; 75; 77; 80; 85; 88; 90; 91; 92; 94; 100; 110; 111; 112; 115; 117; 118; 125; 127; 128; 129; 130; 139.
FW-ND3	Coarse to very coarse friable clay lumps with heavy rounded vitrification on the interior side and an abraded/broken exterior side.	Up to 222mm max L	14; 18; 24; 26; 27; 34; 44; 46; 47; 54; 55; 56; 58; 60; 62; 65; 70; 72; 76; 77; 79; 80; 82; 84; 88; 96; 99; 100; 102; 103; 106; 112; 113; 115; 116; 118; 120; 124; 125; 129; 131.
FW-ND4	Thin curved fragments without any significant vitrification which may be pottery.	<111mm L, most 9-20mm T, up to 24mm T	19; 20; 28; 34; 49; 74; 87; 119.

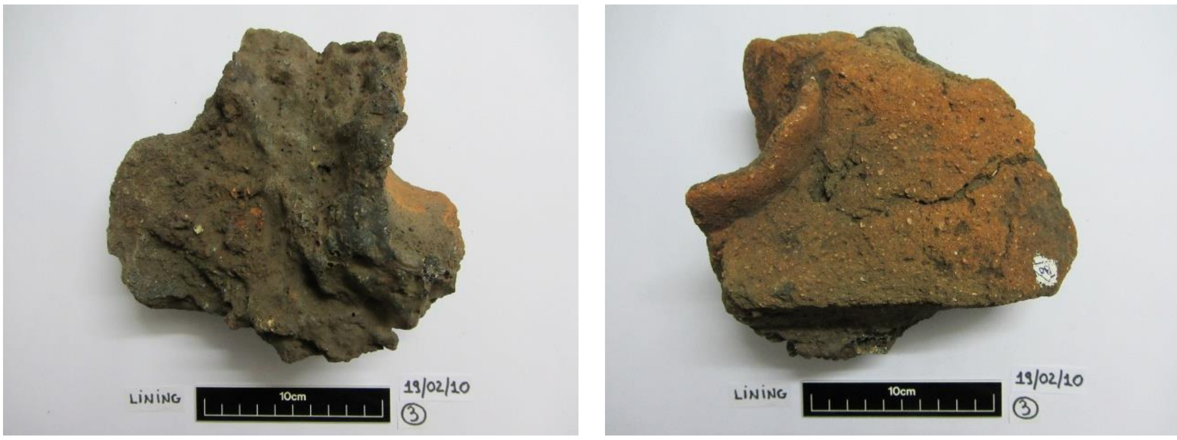
FW1 fragments are the most common. There are some small morphological variations in shape and fabric but they are for the most part very similar. A variety of base and body fragments were found and their general morphological characteristics will be described here. For more detailed descriptions refer to appendix C.4. All examples are curved, suggesting that they were part of circular structures, probably shaft furnaces. The most common base-type flares slightly at the bottom, giving a profile that has been likened to an ‘elephant’s foot’. However, several fragments without this diagnostic flare were also

present but due to their similarity in manufacture and size, were grouped in the same sub-type. The majority are 40-60mm thick at the base, tapering as the height increases to a thickness around 16-30mm. However, not all fragments had their full widths surviving with exterior surfaces heavily abraded, while others suffered from considerable melting on the interior. Their curvatures were prominent enough to estimate inner diameters varying from 240-400mm with most between 300-350mm. This is consistent with many of the plano-convex slag cakes described in chapter 6.2.2.

The majority are made of a medium coarse-fabric dominated by small quartz inclusions <3mm in size. This once again varies slightly with a few examples being slightly coarser or finer. Of interest though are several fragments with fine fabrics, tempered with an organic cereal component. All fragments have vitrification on their interior (concave) surfaces while the exterior (convex) surfaces are of an orangey or reddish oxidised colour (Figure 6.23). For the most part, the vitrification is dull dark grey to black in colour and thin (<5mm). It is solid, medium sandpaper-rough in texture with few or no major projections of material. Some examples have rougher and more agitated surface vitrification but these are rare and tend to correlate with fragments with adhering tuyeres (Figure 6.23); where the internal temperatures were likely to be higher due to the proximity to the air outlet. Others have some rougher coloured patches which are magnetic suggesting high iron content in these areas. All the furnace wall fragment bases (the part in contact with the ground) are flat and baked hard or lightly vitrified (Figure 6.23), in some cases with a thin layer of porous slag. This suggests that the furnace walls were built on a hard, flat surface, perhaps on a stone base or plinth.

Of particular interest, are the parallel impressions or striations present on the surfaces of many fragments. These occur on both internal and external surfaces but differ in style. The internal linear impressions are vertically aligned, parallel and span the entire length of the fragments (Figure 6.23). These are between 5-15mm wide and no more than a few millimetres deep. Similar impressions were present on some of the exterior surfaces, typically on base fragments. However, these had a tendency to overlap, were at an angle and were not as uniform suggesting that these were finger marks. The other type of marking was noticed on the exterior surfaces of base fragments where a very thin layers of clay (<2mm) appears to have chipped off revealing another surface underneath. These consisted of many fine, tightly packed, sometimes overlapping unidirectional striations (<2mm wide). The internal impressions are possibly marks left by bundled reeds or straw, used to support the clay structure as it was built, while the thin exterior striations suggests a bristled brush was used to smooth the surfaces. The Agaria tribe of Madhya Pradesh, India, have been known to use bundles of straw as support during furnace construction (Keen 2013, 97).

PM47



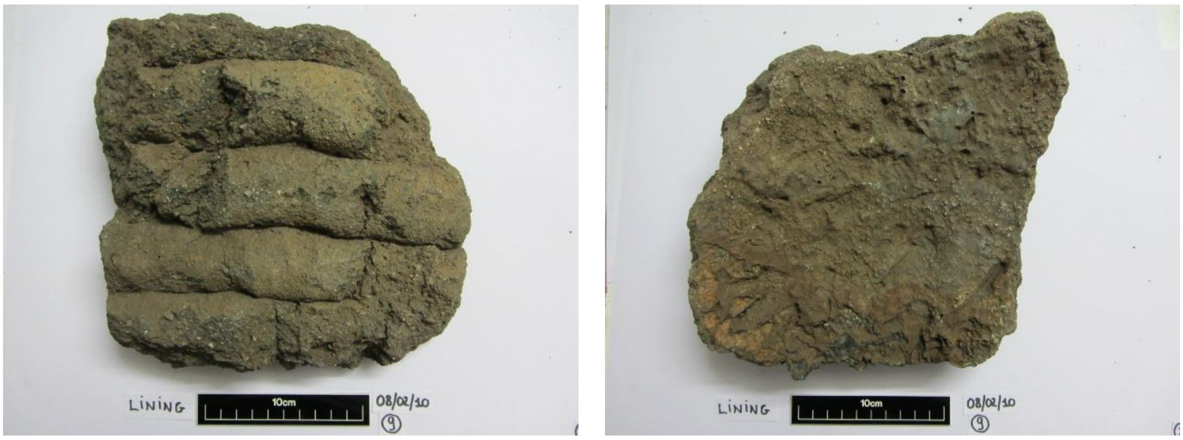
PM99

PM47

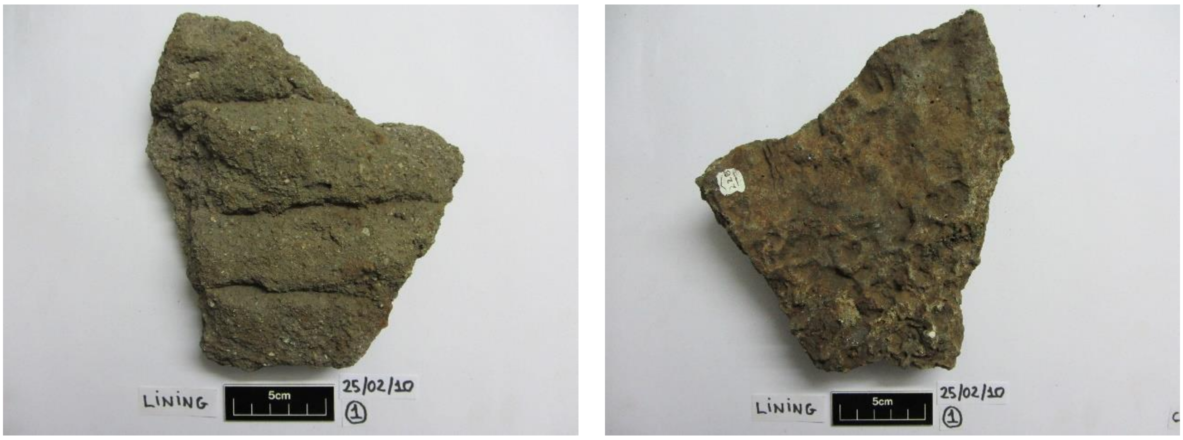
Figure 6.23 - Furnace wall fragments of sub-type FW1. Note the characteristic light vitrification and vertically aligned parallel impressions (top and bottom) as well as the heavier vitrification present on fragments with adhering tuyeres (centre).

FW2 fragments are less common and very different in morphology to those of sub-type FW1. They all display stacked coil construction, thick walls and a coarse to very coarse fabric dominated by medium to large quartz inclusions (<10mm). The exception are those from PM112 which are mid-coarse with fewer, smaller quartz. Some also show signs of an organic component, most probably charcoal. The fragments are very fragmentary with no intact edges remaining but their internal and external surfaces survive in part. They are up to 268mm in length, 222mm in height and have wall thicknesses between 45-90mm. Most are also curved but the majority are too small or damaged for an accurate estimate of original diameter size. Nevertheless, the largest fragment, from PM58, appears to have had a diameter in excess of 500mm.

All fragments have one non-vitrified exterior (convex) surface and one vitrified interior (concave) surface (Figure 6.24). Although the exteriors appear to have suffered considerable abrasion, most retain their original thicknesses. The clays are dark grey and have very distinct horizontal join lines, made by the stacking of large clay coils, 30-50mm wide (Figure 6.24). On the better preserved examples, these coils still retain a rounded shape with a smooth surface. Their interior surfaces are all heavily vitrified (Figure 6.24). The majority of fragments have low to medium rough dark grey to black vitrification, consisting of small to medium rounded projections and undulations. These undulated surfaces appear to have partially formed around charcoal, as evidenced by the large numbers of impressions, up to 30mm in length (Figure 6.24). Most of the vitrified surfaces are solid with few, small spherical voids, but in parts where it has chipped, greater porosity is seen underneath. Some examples have dark reddish-orangey-brown and dark brownish-red patches but none are magnetic. A few also have green glassy material similar to the GS1 sub-type (described below).



PM58

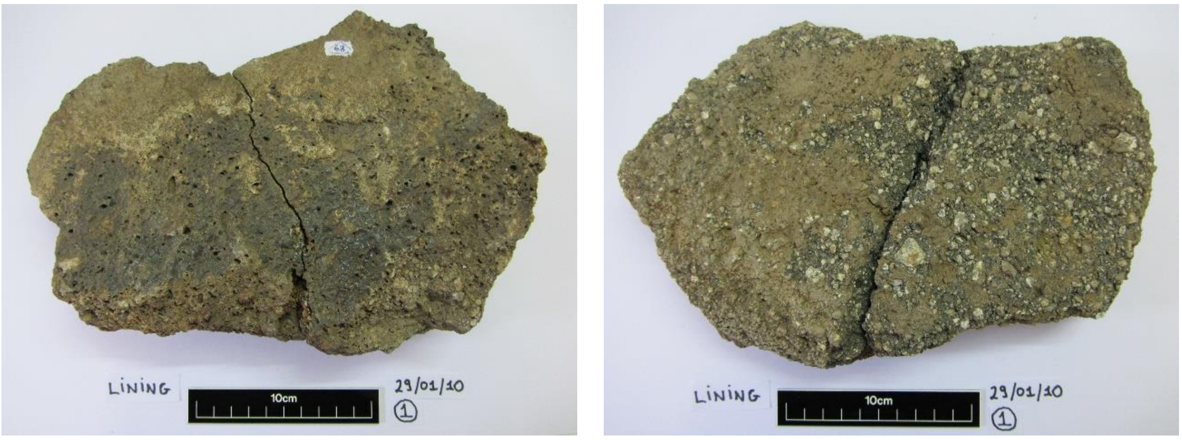


PM119

Figure 6.24 - Furnace wall fragments sub-type FW2. Note the coil construction and heavy vitrification.

Sub-type **FW3** comprises several unusual fragments that share one major morphological trait. They are all straight refractory walls with no identifiable curvature (Figure 6.25). The majority have one vitrified side suggesting that they were associated with metallurgical activities. They have thicker walls than sub-types FW1 and FW2, with most edges broken. They vary in size from 58-267mm in length and 23-80mm in thickness (most 30-60mm). Their fabrics vary considerably. Few examples have fine silty dark brownish-red clay with organic inclusions such as straw or rice husks while the majority are mid to coarse, dominated by quartz inclusions up to 10mm (most <3mm). Their surfaces are similar to other furnace wall fragments, with an orangey or dark brownish-red oxidised exterior surface and a vitrified internal surface (Figure 6.25). Many of the fragments are heavily abraded and several have lost parts of their vitrified surfaces, exposing the dark grey reduced clay that lies underneath. The vitrification varies considerably. Many have thin (<10mm) layers of medium sandpaper-rough vitrification with no major protrusions, while others display thicker and more agitated surfaces with bulbous or sharp protrusions and shallow charcoal impressions up to 50mm. Some also have magnetic orangey-brown or dark brownish-red patches suggesting high iron content in those areas. For the most part, the vitrification is solid with few spherical and globular voids but there is increased porosity underneath, visible where it has chipped off.

Of particular interest are fragments with parts of their edges surviving. A few examples have one unbroken rounded edge suggesting that they are rim fragments (Figure 6.25). Their thickness tapers from the body to the rounded rim edge and there is less vitrification close to these edges. Three examples also have one unbroken flat edge. These are baked hard indicating that they were bases. The relatively poor preservation of FW3 fragments limits further interpretation but they were probably smithing hearth charcoal retaining walls. Refer to chapter 5.1.3 for modern smithing hearth descriptions recorded during the survey.



PM18

PM118

Figure 6.25 - Furnace wall fragments sub-type FW3. Note their lack of curvature and the rounded edge on the fragment at the bottom.

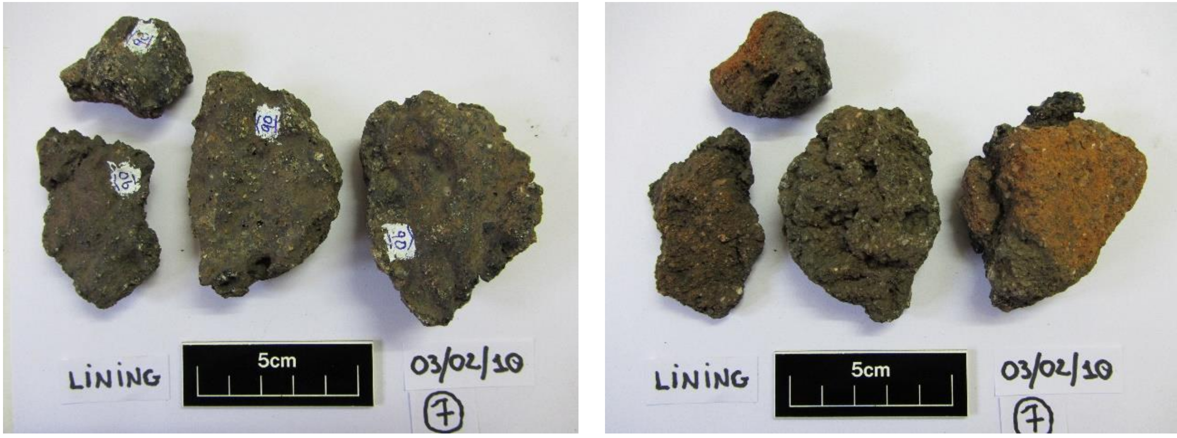
FW4 consists of a singular large, distinctive straight base fragment. It is 260mm long, 156mm in height and 112mm wide at the base, tapering to 73mm at the top (Figure 6.26). However, the exterior surface of the wall is broken so it would originally have been thicker. The ends and base are baked hard suggesting that these are original surfaces. The base is also flat indicating that it was resting on a flat surface. The most distinctive aspect is its composition, made of c.7 stacked T2 tuyere fragments (Figure 6.26). Most are broken, approximately 1/3rd of their original circumferences remain and they appear to have been re-used with reduced fabrics and vitrification present. They have been stacked with the convex side facing up but there is one fragment which is convex side down. These fragments are held together by a reduced, dark grey, coarse clay dominated by medium to large quartz crystals up to 12mm (Figure 6.26). The vitrified side has no major protrusions but it is uneven with smooth to low-rough undulations. It is dark grey to black and solid, except in areas where it is abraded and small spherical voids are apparent. The vitrification also protrudes below the flat base by a couple of centimetres suggesting that there was a depression in the ground in front of it where charcoal may have been heaped.

In the centre of the fragment, resting on the base, is a thin walled tuyere with a complete circumference. There is no clay between the tuyere and the flat base suggesting that it must have been placed on the ground and the wall built around it (Figure 6.26). It is made of a medium coarse fabric with a wall thickness between 12-15mm. It is about 115mm in length but the rim end is missing. The inner diameter is consistent at 36-37mm. The nozzle protrudes about 50mm from the vitrified furnace wall. As a whole, the wall is symmetrical with the main tuyere placed directly in the centre and is likely to have been a smithing hearth wall.

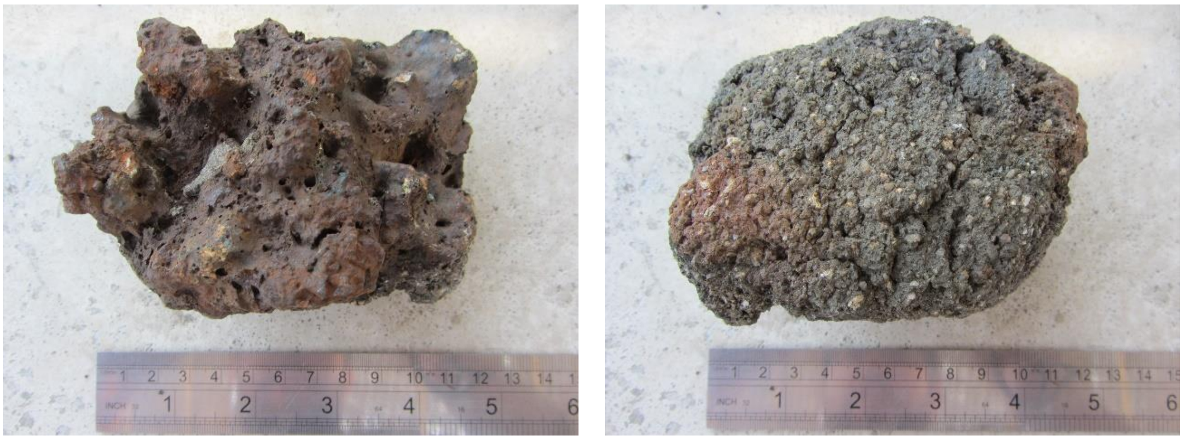
PM103

Figure 6.26 - Distinctive wall fragment sub-type FW4. Note the stacked tuyere construction and the central protruding tuyere.

Many of the furnace wall fragments in the assemblage are small, broken and not diagnostic. Nevertheless, they still retain some attributes which enabled their grouping into four non-diagnostic sub-types (FWND). These will not be described here in detail, refer to appendix C.4 for more information. **FWND1** are small, amorphous and fully vitrified fragments varying in fabric coarseness. **FWND2** are more varied and consist of non-vitrified fragments that have lost the majority of their original surfaces as well as vitrified fragments that have lost their non-vitrified surfaces, making them impossible to identify. They also vary greatly in fabric type from fine to mid-coarse (Figure 6.27). **FWND3** are the most numerous and consist of broken fragments, with heavy vitrification on one side and abraded dark grey/red clay on the other. Their fabrics are all coarse to very coarse, dominated by quartz inclusions, mostly <5mm in size but up to 17mm (Figure 6.27). A few have vitrification resembling that of the exterior of crucibles (discussed below). **FWND4** are small, thin fragments with a slight curvature. They are all made of a fine to low-coarse fabric containing very few small quartz inclusions, <1mm, and dominated by a cereal grain organic component. None are vitrified and the majority of the surfaces are either orangey in colour or darker orangey-grey suggesting that they were not associated with metallurgical activities. It is possible that these are pot fragments.



PM40 – FWND2



PM46 – FWND3

Figure 6.27 - Non-diagnostic furnace wall fragments sub-type FWND2 (top) and FWND3 (bottom). Note the coarser fabric of the FWND3 fragment.

6.2.5 Tuyeres

Tuyere fragments were very common and a total of 907.3kg were collected, accounting for 6% of the entire assemblage by weight. All tuyeres recovered were fragmentary, with none surviving whole. However, many were complete enough to estimate original circumference. Most also had surviving parts of either the rim or nozzle end enabling the identification of four main sub-types and four non-diagnostic sub-types. A few examples had complete circumferences and large parts of their length still intact, allowing original size and shape to be determined. The proportion of each sub-type as well as the number of sites on which they were found is illustrated in figure 6.28. By far the most dominant sub-type is T2, accounting for 69% of the tuyeres and present on 50 sites. The next most common are T1 and T3, both accounting for 16% and 9% respectively and each found on 9 sites. The others, including all the non-diagnostic sub-types make up 3% or less and are present on 3 or less sites, with the exception of the fully non-diagnostic fragments which were found on 11 sites. The main characteristic features and size range of each tuyere sub-type and the sites on which they were found is given in table 6.5.

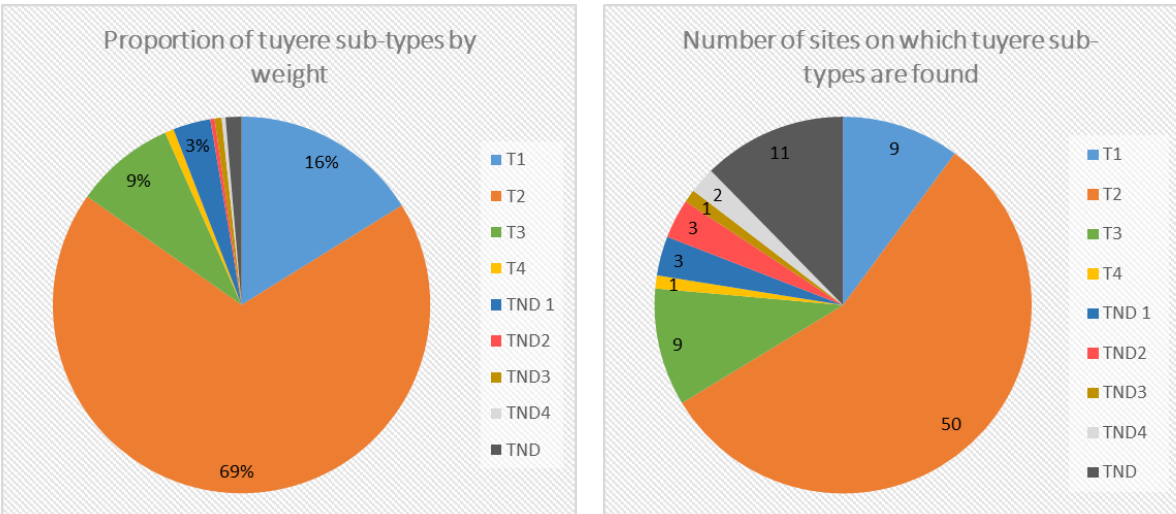


Figure 6.28 - Proportion of tuyere sub-types by weight (907kg) (left) and number of sites on which they were found (right).

Table 6.5 - Main characteristic features, size range of each tuyere sub-type and the sites on which they were found. L – length, ID – internal diameter and WT – wall thickness.

Type	Characteristic Features	Size Range	Sites Present (PM)
T1	Small inner diameter; very slight inner diameter taper towards nozzle; thin to medium wall thickness; no rim flare; added clay lump on exterior tuyere surface.	Up to 142mm L (incomplete), 21-30mm ID nozzle, 25-37mm ID rim, 7-15mm WT	3; 28; 31; 58; 60; 62; 63; 104; 133.
T2	Medium to large inner diameters; heavily tapering inner diameter towards nozzle; medium wall thicknesses; flaring rim.	Complete frags 92-155mm L (one incomplete 181mm), 30-45mm ID nozzle, 65-90mm ID rim, 7-20mm WT - most 10-15mm, two 17-25mm	Certain: 36; 44; 45; 46; 47; 49; 52; 56; 57; 58; 63; 64; 74; 76; 77; 79; 80; 83; 84; 85; 88; 95; 99; 100; 106; 112; 113; 116; 118; 124; 125; 127; 128; 132; 134. Probable: 21; 22; 24; 34; 40; 54; 55; 73; 74; 77; 79; 83; 88; 91; 92; 93; 100; 111; 119; 120; 125; 128; 130; 132; 134.
T3	Medium to thick walls; medium to large inner diameter; no or very little inner diameter taper to nozzle (almost tubular).	Up to 161mm L (incomplete), 37-60mm ID, most 18-50mm WT	Certain: 54; 65; 75; 80. Probable: 55; 56; 88; 102; 118.
T4	Small inner diameters; very slight inner diameter taper to nozzle (almost tubular); very thin walls; long?	<70mm L (incomplete), 30-32mm ID rim, 25-28mm ID nozzle, 4-11mm WT	74.
TND1	Well preserved but no ends; no apparent rim flare; tapering diameter to nozzle; medium coarse fabric.	Up to 167mm L, 30-35mm ID nozzle, 40-50mm ID rim	112; 119; 128.
TND2	Very fragmentary flattened rim fragments.	13-20mm WT, 60-70mm ID rim?	18; 125; 130.
TND3	Distinctive small diameter tuyeres; very coarse fabric; tubular?; medium thick walls.	Up to 60mm L (incomplete), 20-30mm ID nozzle, 15-17mm WT	35.
TND4	Very fragmentary; fine fabric; thin greyish white vitrification on exterior.	fragmentary	60; 106.
TND	Non-diagnostic fragments.	fragmentary	46; 56; 60; 99; 100; 103; 106; 108; 110; 112; 120; 129.

The majority of the tuyere fragments were grouped into four main sub-types (T1, T2, T3 and T4). The rim and nozzle inner diameters and wall thickness size ranges of the best preserved examples from each type is illustrated in figure 6.29. Since the majority of the tuyeres were not complete, most diameter measurements were estimated based on the curvature of the fragments. It is also worth mentioning, that no tuyere survived to their original length with most missing one end, either the rim or nozzle, so accurate length measurements or estimations are not given here. Nevertheless, the inner diameters and wall thicknesses presented below give a good representation of the size properties of each sub-type. All tuyeres appear to have been manufactured in the same way. They were all moulded around a cylindrical object, most probably a shaped piece of wood. This is evident from the internal horizontal slip marks created by the removal of a mould when the clay was still wet. In addition, many of the better preserved examples have large elongated depressions on the external surfaces resembling finger marks, further evidence to support this theory. This method is also well documented in the ethnographic records (Keen 2013, 99; Mishra 2003).

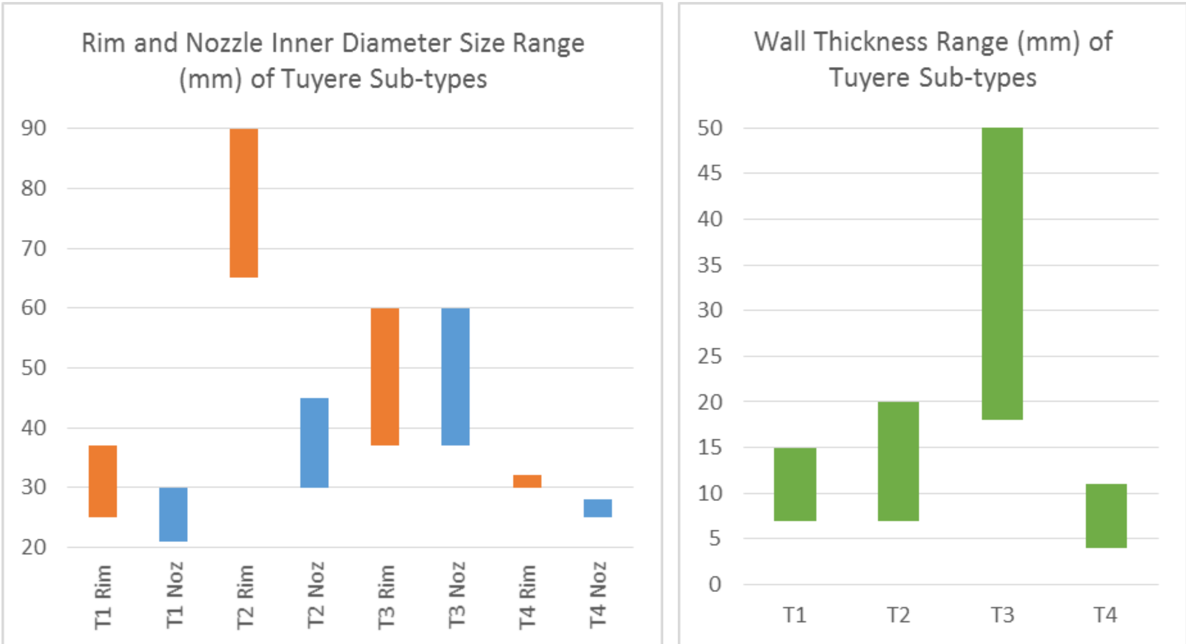
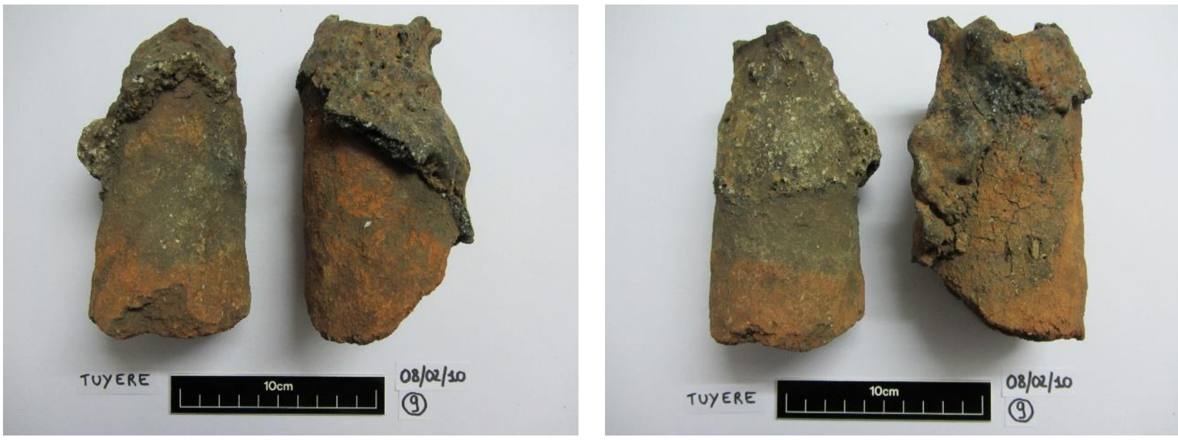


Figure 6.29 – Rim and nozzle inner diameter (left) and wall thickness (right) size range of the better preserved examples in each main tuyere sub-type.

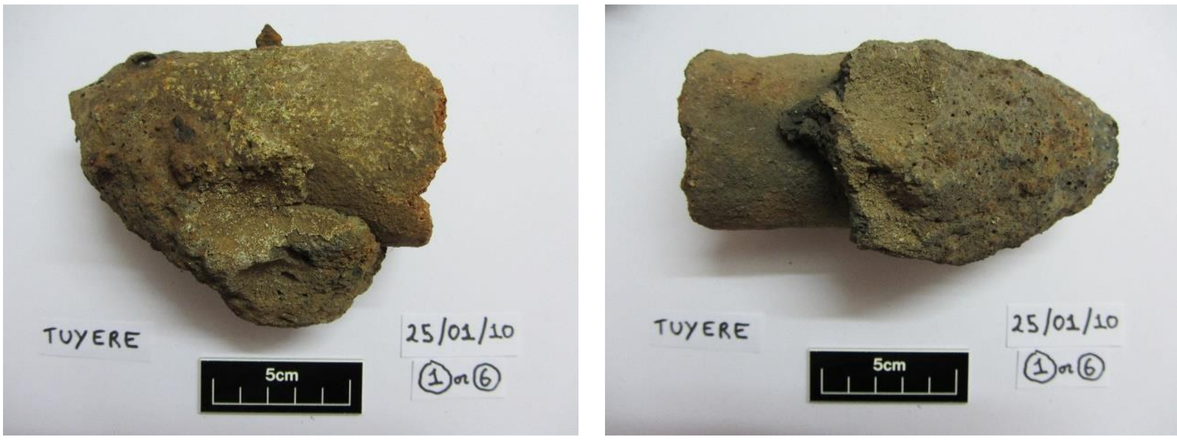
On the whole, **T1** fragments were relatively well preserved with most having complete circumferences, however, most rim ends were missing. The major characteristics of this tuyere type are their small inner diameters which taper very slightly towards the nozzle end and their thin to medium wall thickness. Their sizes range from 25-40mm inner diameter at the closest surviving part to the rim and 21-31mm at the nozzle end. The walls are 7-18mm thick and the most complete fragment survives to a length of 146mm. Their fabrics are medium to coarse, dominated by small quartz grains, mostly <2mm in size. They vary in colour from a brownish oxidised orange to dark grey reduced. The inner surfaces and rim ends tend to be more orange in colour while the nozzle ends are dark grey to black and heavily vitrified (Figure 6.30).

Of particular interest are several fragments from PM3, PM28 and PM31 which have large lumps of clay adhering to the exterior surfaces close to the nozzle end. Although most do not have this adhering clay, many have dark patches indicating that they once did. The clay is heavily vitrified on the nozzle side and comes to an abrupt end further up the tuyere suggesting that this was where it made contact with the interior furnace wall (Figure 6.30). Underneath the vitrification, is dark grey reduced clay of varying coarseness (mostly coarser than the tuyere fabrics) and 20-38mm in thickness. The exterior vitrification has finger imprints suggesting that the clay was intentionally moulded to the extremities of the tuyere and not just melted from the furnace wall (Figure 6.30).

Some fragments have thinner vitrification, <14mm thick (Figure 6.30). Many of these also have reduced clay underneath suggesting that a layer of clay was added at the nozzle end. All the vitrification is broken close to the nozzles suggesting that the tuyeres were unlikely to have protruded more than 100mm inside the furnace. Most of the vitrification is medium rough, rounded in appearance with greyish-white partially melted quartz crystals visible on the surface, but some examples do have rougher, more uneven vitrification. A couple of examples also have magnetic dark brownish-red patches. It is worth noting that the vitrification on the tuyere nozzles appears to be at an angle (Figure 6.30). It reaches further up the tuyere on one side than the other suggesting that they were placed in the furnace wall at an angle, most probably with the nozzle facing down into the furnace.



PM58



PM122

Figure 6.30 - Tuyere fragments sub-type T1. Note the angled vitrification and the large vitrified clay lump with finger marks (bottom).

T2 tuyere fragments are the most numerous and most common in the assemblage. There are well-preserved examples with complete circumferences and one surviving end as well as small broken fragments. These latter have been attributed to this sub-type due to similar morphological characteristics or their association with better preserved examples. Tuyeres of this sub-type are defined by their flaring rim and heavily tapering inner diameters towards the nozzle end (Figure 6.31). The flaring rims were likely to have been shaped by hand, as the wall thickness tends to be thinner and there are usually no internal slip marks close to the rim. The rim edges are either rounded or flattened (angular). The most complete examples are between 92-181mm in length. However, the nozzle ends are often heavily vitrified and it is not possible to judge how much of the tuyere melted in the furnace. Their inner diameters vary from 65-90mm at the rim to 30-45mm at the nozzle end. Their fabrics are mostly medium-coarse with quartz inclusions, <2mm, but some are medium to coarse with quartz up to 5mm in size. Their wall thicknesses vary from 7-20mm with most between 10-15mm. Most of the exterior and interior surfaces are orange or reddish-orange in colour but the fabric gets darker with a progression from light to dark grey closer to the nozzle end (Figure 6.31). Nozzle ends also have dark grey to black medium rough vitrification, <15mm thick. The majority of the vitrification is molten with well-rounded features and varying proportions of light grey, partially melted, quartz inclusions. However, there is some variation with uneven and rough examples or even a few almost entirely smooth and glassy black. Magnetic dark brownish-red patches are rare but present on some examples.

In many cases the vitrification appears to have broken off abruptly (in a neat straight break) indicating where the furnace wall started. Similar to T1 fragments, the vitrification is not even on all sides suggesting that the tuyeres were placed at an angle in the furnace wall (Figure 6.31). This is confirmed by the tuyere fragments with adhering furnace wall. The majority of these only have small, abraded, non-diagnostic furnace remains but a few are still embedded in large portions of furnace wall. All appear to be sub-type FW1 and the tuyeres are placed at a 30-40 degree angle with the nozzle facing down. They protrude up to 70mm into the furnace. Some tuyeres were placed in the furnace wall at a slight sideways angle suggesting that some furnaces may have had more than one tuyere. Their rim ends appear to have been almost flush with the exterior of the furnace wall, protruding a maximum of 30mm (Figure 6.31). The best preserved fragments show that the tuyeres were placed close to the base of the wall (30-60mm) and that the nozzle ends were either protruding (inside) below or at the same level as the furnace base (Figure 6.31). This suggests that the base of the furnaces had a central depression.

PM132

PM113

Figure 6.31 - Tuyere fragments sub-type T2. Note the flaring rims and the placement of the tuyere in the furnace wall section (bottom).

T3 tuyeres are much less common, and are generally in a poor state of preservation, consisting of small fragments without complete circumferences. They differ from the other two types by having thicker walls, between 18-50mm and very little to no internal taper towards the nozzle end. They have medium to large inner diameters, between 37-60mm, with most around 40mm (Figure 6.32). All fragments except one are missing the rim ends. The width of the tuyeres do not seem to widen significantly towards the rim suggesting that they were likely to have been straight-walled and tubular. Most have medium-coarse fabrics with quartz inclusions, <2mm, but others vary significantly from low coarseness with fewer quartz to very coarse dominated by quartz inclusions up to 9mm (Figure 6.32). Since the nozzle ends survive better, the majority of the fragments are of a medium to dark grey reduced colour but they do have some oxidised orangey clay on the internal surfaces and further away from the nozzle ends (Figure 6.32).

Most examples with surviving nozzles are vitrified but it also varies greatly. A few examples have vitrification on the extremities of the nozzle, suggesting that they did not protrude much into the furnace (<100mm) while on others the thin vitrification reaches further up the tuyere. The vitrification is mainly dark grey to black, of medium roughness with rounded features (Figure 6.32). It is sometimes black and glassy on the nozzle extremity where the temperature was likely to have been higher, and on a few examples there are charcoal impressions. There are also some whitish-grey partially melted quartz crystals dotted within this vitrification. Similar to the other tuyere sub-types, the vitrification extends further on one side of the tuyere than the other suggesting that they were placed in the furnace wall at an angle with the nozzle facing down (Figure 6.32). Two of the larger examples also have thick layers of additional clay placed on the top.

PM80

PM65

Figure 6.32 - Tuyere fragments sub-type T3. Note the thick walls and the angled vitrification at the nozzle end (bottom).

T4 tuyeres were restricted to one site, PM74. Their major morphological characteristics are very thin walls, between 4-11mm, and a small inner diameter with a very slight taper towards the nozzle end. These are almost tubular. Their inner diameters range from 30-32mm at the closest surviving part to the rim, to 25-28mm at the nozzle end. The better preserved examples survive to a length of 61-70mm but since all rim ends are missing their original length cannot be estimated (Figure 6.33). Their fabrics are fine to low-coarse with few or no quartz crystals but perhaps some organic inclusions. They range in colour from pale orange at the closest surviving ends to the rims, changing to light and dark grey close to the nozzle ends. All fragments also have similar vitrified nozzle ends. The vitrification is pale to glassy black in colour ranging from smooth to low sandpaper-rough (Figure 6.33). There are also a few whitish-grey partially melted quartz crystals dotted in the vitrification, which is thin, between 3-7mm, and on all examples appears to have broken off abruptly most likely where the furnace wall started. As with all other tuyere sub-types, the vitrification is uneven suggesting that the tuyeres were placed at an angle of approximately 30˚ (nozzle down) in the furnace or hearth structure and did not protrude more than 50mm inside the furnace (Figure 6.33). This is supported by one example with an adhering fragment of furnace wall. The tuyere is angled downwards but also at a slight sideways angle, suggesting perhaps, that more than one tuyere was placed in the furnace wall. However, the poor preservation limits further interpretation.

There is an almost complete tuyere fragment made of the same fabric but appears to be a variation on this sub-type. It is 160mm in length with the rim end and extremity of the nozzle missing (Figure 6.33). The inner diameter at the nozzle end is 22mm and about 23mm at the furthest surviving end, towards the rim. Therefore, unlike the others, the inner diameter does not taper but the thickness of the walls do. The walls are 8mm thick at the rim end tapering to 3-4mm thick at the nozzle end. One side of the tuyere is dark to light grey while the rest of it is light orange in colour (Figure 6.33). It seems that this tuyere was not used but may have been fired with the reduced side facing the heat source.

PM74

PM74

Figure 6.33 - Tuyere fragments sub-type T4. Note the thin walls and the angled vitrification at the nozzle end (top) as well as the better preserved example with one reduced side (bottom).

In addition to the four main tuyere types, several non-diagnostic sub-types were defined (TND1, TND2, TND3 and TND3). These are tuyere fragments that are on the whole poorly preserved but with enough surviving morphological features to be grouped into separate categories. These will not be described here in detail. Refer to appendix C.5 for more information. **TND1** fragments have both rim and nozzle ends missing, making identification difficult. On the whole they are thicker walled than the T2 examples but with a similar tapering inner diameter from rim to nozzle. They also have no evidence for a flaring rim. **TND2** are small rim fragments but once again do not appear to flare. Their fragmentary condition makes them non-diagnostic. **TND3** are small nozzle fragments with complete circumferences, surviving no more than 60mm in length. They have small inner diameters and relatively thick walls made of a very coarse fabric (Figure 6.34). **TND4** are non-diagnostic body fragments with relatively thin walls and unusual vitrification. Their exterior surfaces are dominated by a thin layer of greyish-white vitrification not found on any other tuyere sub-type (Figure 6.34).

PM35 – TND3

PM60 – TND4

Figure 6.34 - Non-diagnostic tuyere fragments TND3 (top) and TND4 (bottom). Note the coarse fabric of the TND3 examples and the whitish-grey vitrification of the TND4 examples. .

6.2.6 Crucibles

A total of 58.5kg of crucible fragments were collected, accounting for 4% of the entire assemblage by weight. All crucibles recovered were fragmentary with none surviving whole, however, many had enough surviving characteristics to enable the identification of three sub-types. A few better preserved body fragments allowed more accurate measurements to be taken. The proportion of each sub-type and the number of sites on which they were found is illustrated in figure 6.35. The most dominant sub-type is C1, accounting for 61% of the crucible fragments. C2 and C3 contributed 18% and 19% respectively. The most common sub-type was C2 found on 8 sites while both C1 and C3 were found on 6 and 5 sites respectively. It is also important to mention that due to poor preservation, 2% of the fragments were non-diagnostic but were likely to be of sub-type C2. The main characteristic features and size range of each crucible sub-type and the sites on which they were found is given in table 6.6.

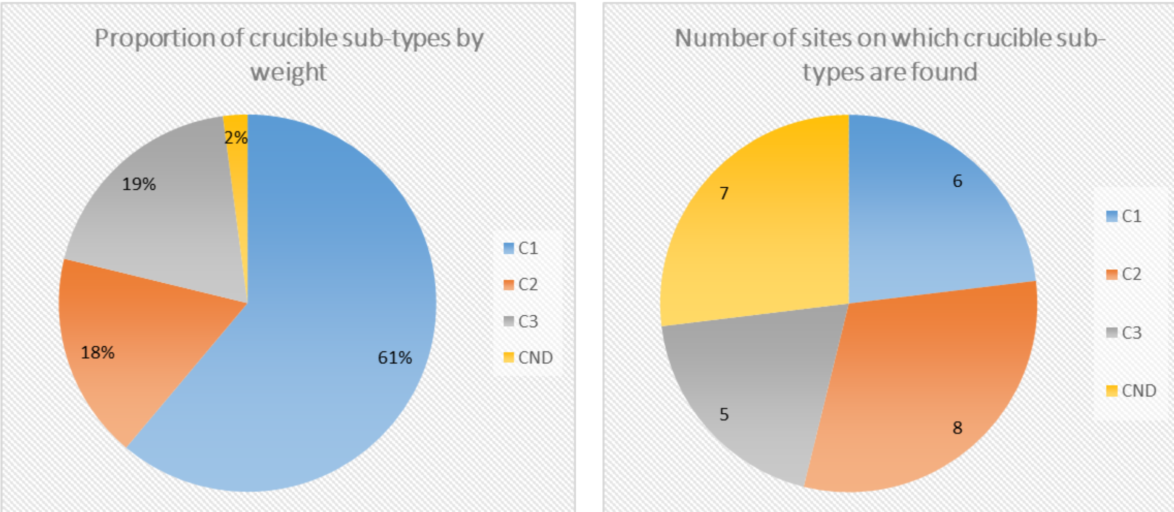


Figure 6.35 - Proportion of crucible sub-types by weight (59kg) (left) and number of sites on which they were found (right).

Table 6.6 - Main characteristic features, size range of each crucible sub-type and the sites on which they were found.

Type	Characteristic Features	Size Range	Sites Present (PM)
C1	Large size range; flat base; conical lid.	Internal chamber 25-119mm diameter and 25-63mm height; external height 75-120mm; wall thickness 5-25mm	60; 62; 65; 66; 67; 106.
C2	Small size range; domed base; domed lid.	Internal chamber 30-55mm diameter and 30-50mm height; external height 55-90mm; wall thickness 3-17mm	18; 19; 54; 58; 88; 119; 128; 133.
C3	Large size range; flat or slightly domed base; domed lid.	Internal chamber 48-103mm diameter and 50-55mm height; external height 65->75mm; wall thickness 5-25mm	74; 75; 101; 102; 103.
CND	Non-diagnostic fragments.	Very fragmentary?	9; 18; 84; 87; 89; 91; 102.

The majority of the crucible fragments were grouped into three sub-types (C1, C2 and C3). The inner chamber diameter and height, wall thickness and external height ranges of the better preserved examples in each sub-type are illustrated in figure 6.36. It is important to note that most of the larger C3 examples were not well preserved. Their chamber and external height could not be accurately measured and are likely to be much larger than presented in figure 6.36. Nevertheless, it shows that there was significant size variation within the same crucible types. C1 crucibles are, on the whole, the largest, closely followed by C3 crucibles with C1 being smaller, particularly in inner chamber diameter. Although larger crucibles were wider and generally taller with thicker walls, they did not always have larger inner chamber heights, suggesting that greater volume was achieved by making the crucibles wider.

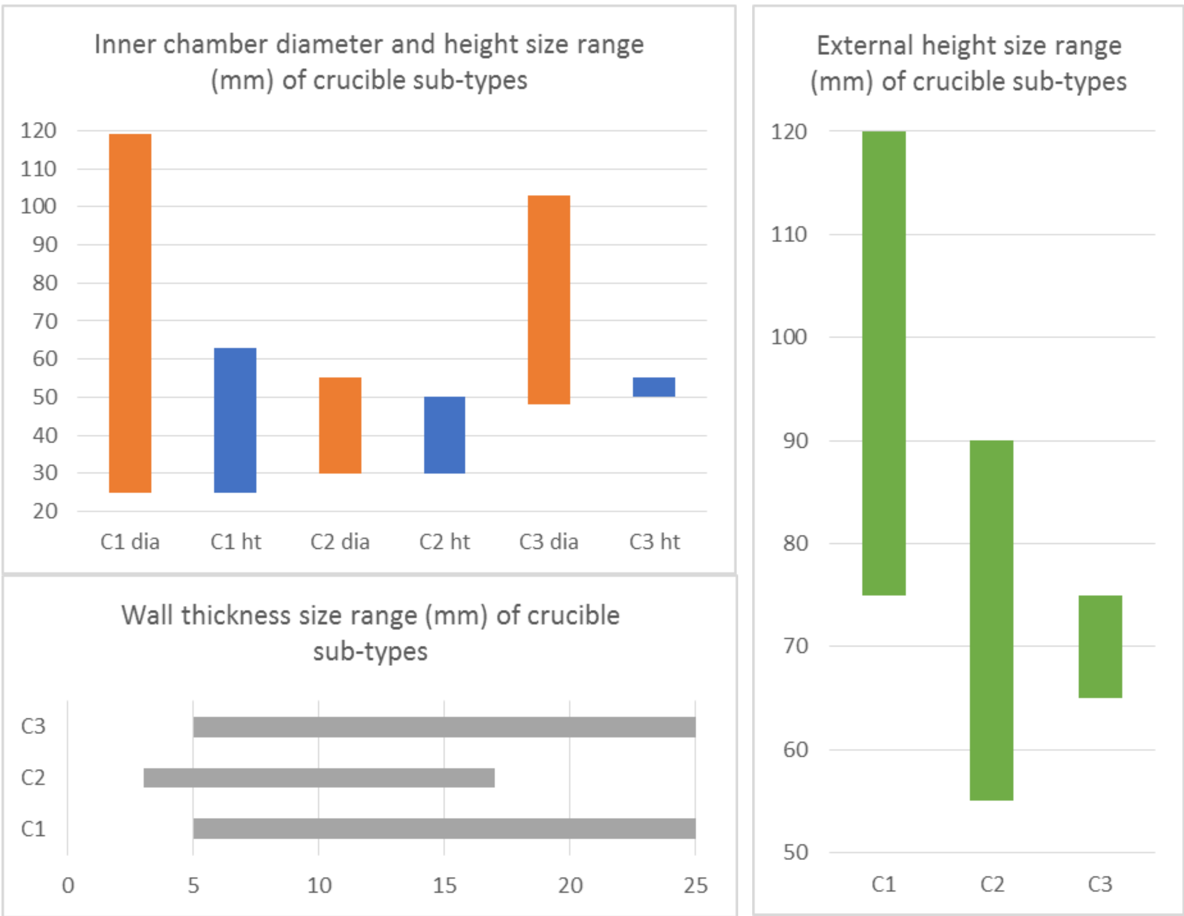


Figure 6.36 - Inner chamber diameter and height (top left), wall thickness (bottom left) and external height (right) ranges of the better preserved examples in each crucible sub-type. Note that only a few C3 examples were well preserved and that the internal chamber height and external height range are likely to have been much higher than represented here, at least up to 65mm in internal chamber height and 90mm in external height.

All crucibles appear to have been manufactured in the same way as they consist of similar fabric types. The main bodies are all of a fine black fabric with many voids apparent in section. These are usually elongated, <4mm in length, and must represent the charred remains of the rice husk temper which has been identified in previous studies (Balasubramaniam *et al* 2007; Lowe 1989a; 1989b). Wall thickness varies greatly depending on crucible size, but as a general rule, it is thickest at the base and becomes progressively thinner towards the rim.

The exteriors of the crucibles are dominated by a highly vitrified coarse quartz-rich clay layer which appears to have been applied over a significant proportion of the main body. The vitrification varies in colour from dull dark grey to glassy black and translucent dark green, dotted with whitish-grey, partially melted quartz crystals. It is usually medium sandpaper-rough with well-molten rounded features and no major protrusions of material. This clay layer appears to be a continuation of the lid fragments and are probably made of the same material, whereby excess clay from the lids was smeared over the crucible sides to form a tight seal (Figure 6.37). On most examples, it stretches down to about two thirds of the crucible height with the bottom part and base of the crucible being left uncoated. These bottom parts have thin black glassy vitrification more consistent with the exposed crucible body. Most bases also have charcoal impressions suggesting that they were placed on top of charcoal. The exterior coarse clay lining thins gradually down the crucible, the inverse of the main body, leaving a relatively uniform wall thickness (Figure 6.37).

The interior of the crucibles are also very similar across the entire assemblage. They consist of an inner chamber with straight sides and flat or slightly concave base. The chamber varies in size depending on the overall crucible size but all share similar morphological properties. The better preserved fragments have a black glassy fin adhering to the inside wall, usually a horizontal line several centimetres above the crucible base (Figure 6.37). This glassy slag looks identical to the GS2 fragments discussed in chapter 6.2.7. The fin constitutes the non-metallic impurities of the crucible charge which melted and turned into a glassy slag during the process. While the denser molten steel sunk to the bottom of the crucible, the impurities in the form of this slag, being less dense, floated above it. Hence, the fin represents the upper limit of the ingot. When the crucibles cooled, the metal ingot and the glassy slag solidified and could easily be separated. These fins are usually triangular in profile with the thickest parts adhering to the crucible wall and are broken where they would presumably have extended across the top of the ingot (Figure 6.37). The underside of these fins tends to be textured by gas voids (porous) while the top surfaces are generally smooth.

Below the fin, the chamber walls are usually lined with a very thin coating of the same black glassy slag (Figure 6.37). This coating is once again textured with numerous small gas voids, giving it a honeycomb-like appearance. Above the fin, the walls have dark brownish-red rusty patches and few metallic prills (up to 3mm) which are magnetic. These patches and prills are also common on the underside of the lids (Figure 6.37). In a few cases, the slaggy fin is not quite horizontal but angled suggesting that the crucibles may have moved or been dislodged while in the furnace or after removal. Since the glassy slag fins represent the upper limit of the steel ingot, it is possible to estimate the approximate size or volume of the ingot. In most cases the ingot seems to occupy approximately half to two thirds of the inner chamber volume of the C1 and C2 crucibles but only a quarter to half of the C3 crucibles.

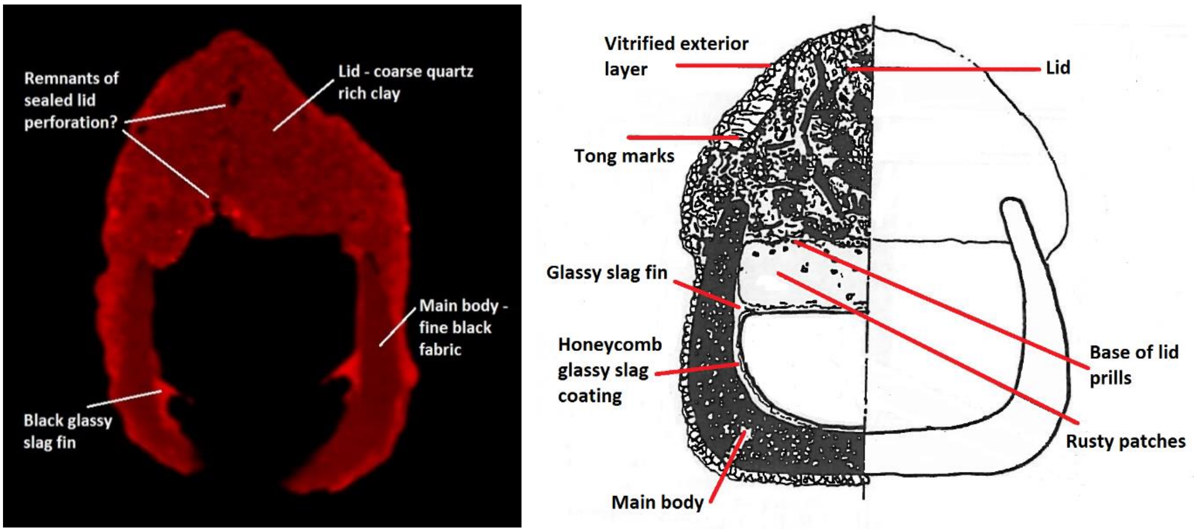


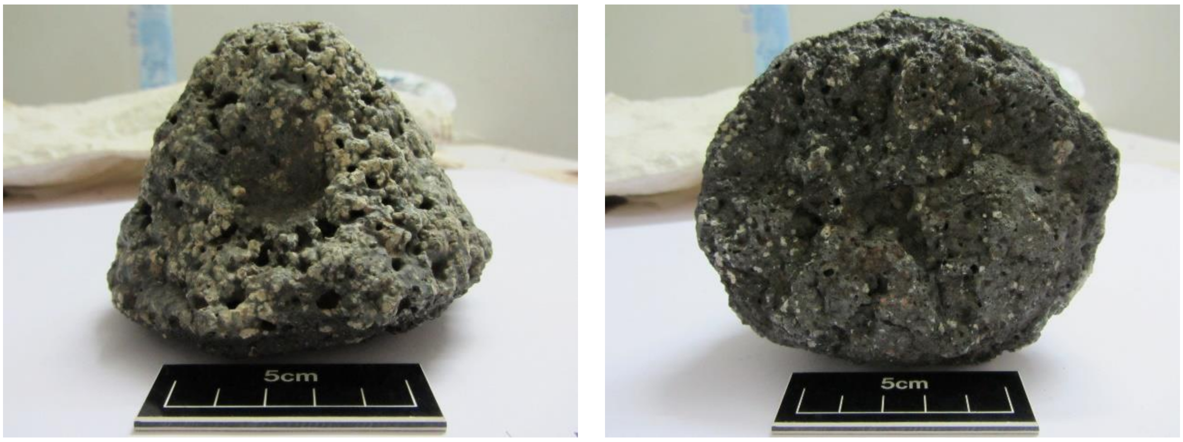
Figure 6.37 – CT scan of crucible (left – adapted from Juleff et al 2011, 30) and crucible schematic (right – adapted from Lowe 1989a, 734) showing the main morphological features. Note the tapering of the main body fabric towards the rim.

The major differences between the three crucible sub-types are their size range and shape. Sub-type **C1** displays the largest size ranges with examples 75-120mm in external height, 5-25mm in wall thickness, 25-119mm in internal chamber diameter and 25-63mm in internal chamber height. The major defining features are their conical-shaped lids and flat bases (Figure 6.38) although the smaller examples sometimes have slightly convex bases. On the whole, the lids of the larger fragments are less pointed than those of smaller examples but always make up a significant proportion of the whole crucible; on average about half of the total crucible height. The majority of the lids have two angular impressions on opposite sides of the cone shape (Figure 6.38) suggesting that they had been moved with tongs when the clay was soft, either for placing into the furnace or for handling during and removal. Although the majority of the lid fragments do not appear to be perforated, a few of them do have one central perforation.

Three fragments from PM65 have a central hole about 3mm in diameter and in one example it clearly goes all the way through the lid. Two of these fragments also have an external impression around the perforation, 12-13mm in diameter and about 10-15mm deep (Figure 6.38). A fragment without a perforation in the same location, has an additional lump of clay protruding from the crucible lid centre. This lump is located where a hole might be expected and could be material intentionally added to seal a hole. The lids with perforations seem to have some dark brownish-red patches on the outside surface (which may be corrosion) indicating that some of the molten metal may have escaped.

The majority of the crucible internal surfaces are free of any impressions. However, some crucibles from PM60 appear to have very small charcoal impressions or inclusions on the underside of the lids (<5mm). This suggests that charcoal or wood may have been one of the ingredients put into these crucibles.

PM60



PM67

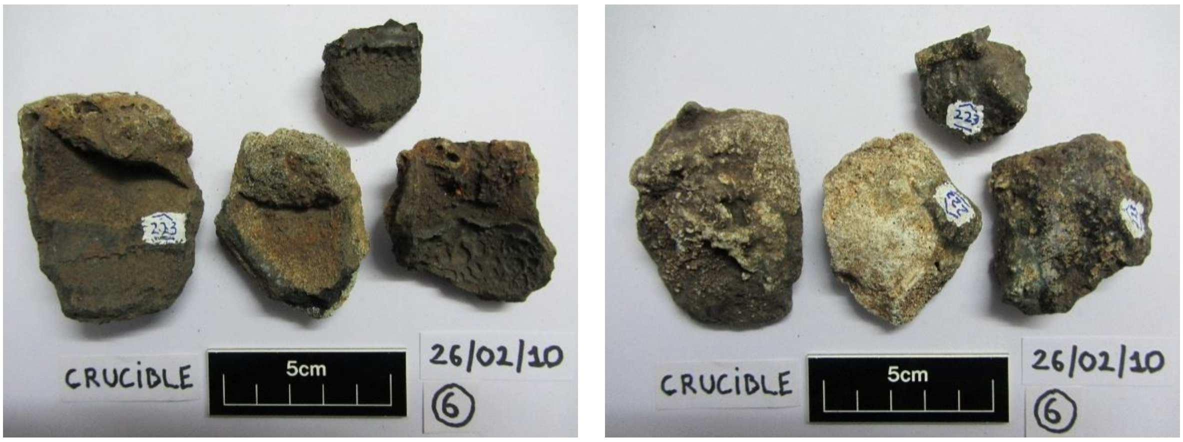
PM65

Figure 6.38 - Sub-type C1 crucible base and lid fragments. Note the conical shape of the lids, the characteristic tong marks and the perforations in the examples at the bottom.

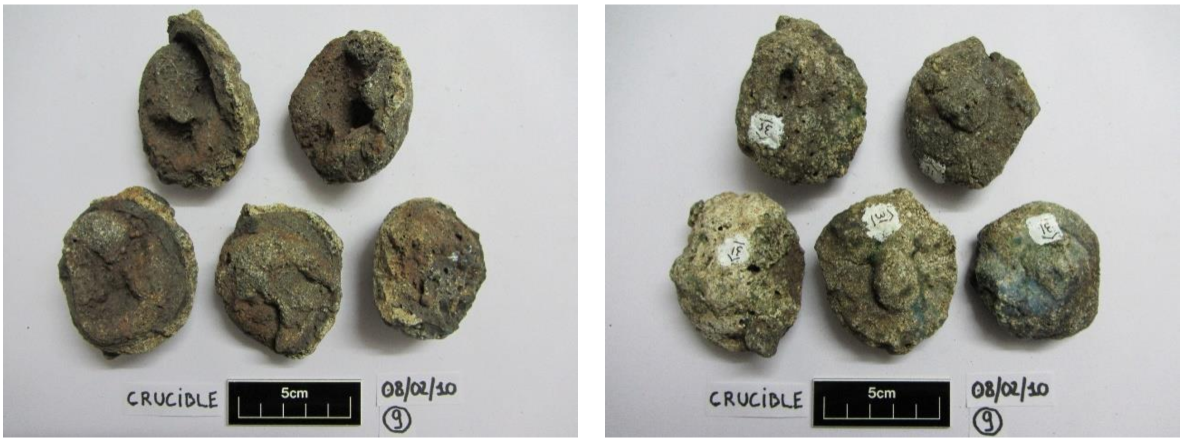
The **C2** crucible fragments are smaller than the other two sub-types. They range in size from 55-90mm in external height, 3-17mm in wall thickness (most 8-15mm), 30-55mm in internal chamber diameter and 30-50mm in internal chamber height. Their main defining features are their small domed lids and convex bases (Figure 6.39). It is important to note that crucibles of this type are often deformed, which could be due to their thinner walled construction. The bases are almost hemispherical in profile and, unlike the small C1 crucibles, the interior base profile is also curved. In a few cases the external base profile of some crucibles appear almost pointed or conical but this may be due to the melting of the external wall, dripping down to distort the base.

The lids are generally quite small, only contributing about a quarter to a third of the total crucible height (Figure 6.39). It may also be significant that no lids or crucible body fragments have tong marks as seen in the C1 crucibles. Two lid fragments however, from PM88, appear to have small perforations or intentionally made depressions in their centres. The holes are conical shaped with a wider diameter at the top (<15mm) tapering as it goes into the lids (<8mm). It seems as if a long thin object was pushed into the lids and rotated around but there is no evidence that they penetrated entirely through the lid. A few fragments from PM58, have small rounded vitrified knobs or lumps in the centre of their lids (Figure 6.39). This additional clay (of the same composition as the lids) may have been added to plug holes but since they no longer have any external evidence of these, it cannot be verified.

PM54



PM128

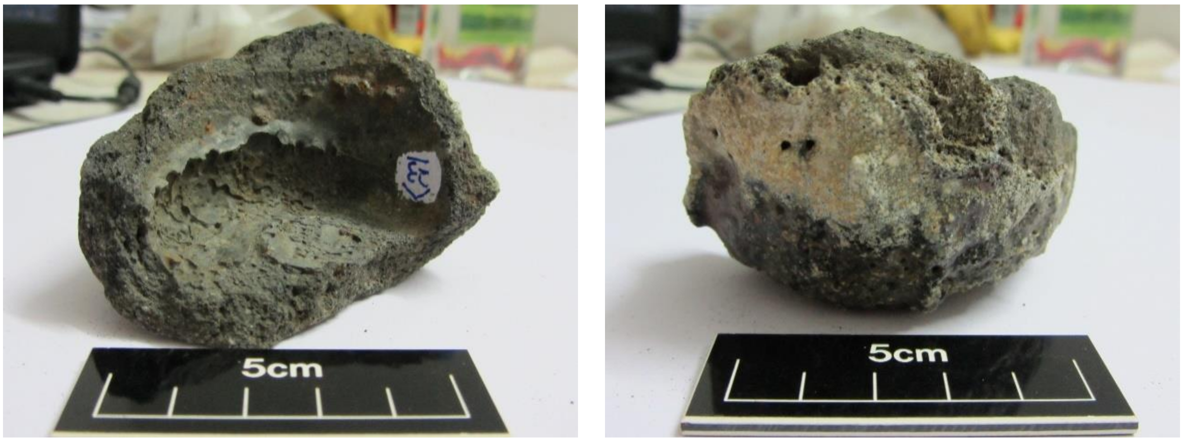


PM58

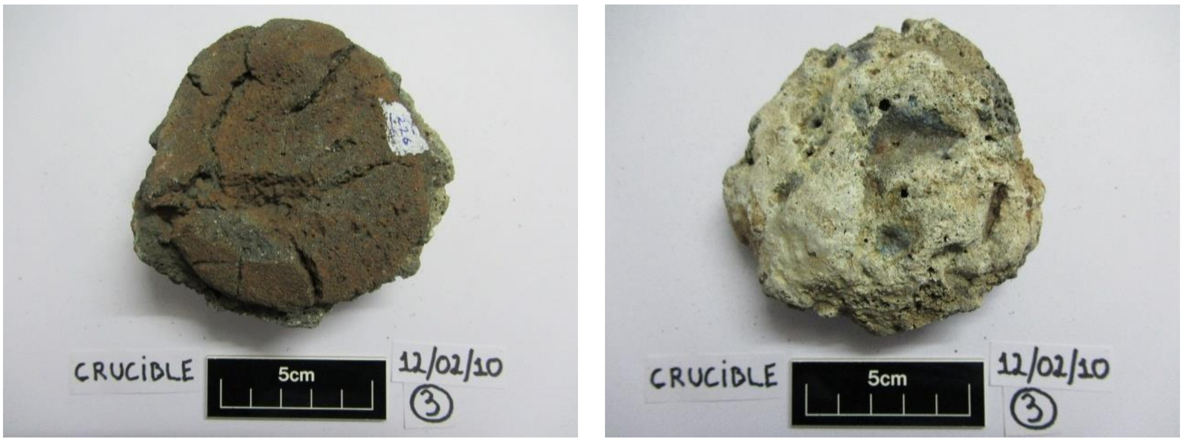
Figure 6.39 - Sub-type C2 crucible base, body and lid fragments. Note the small size, convex bases and small domed lids as well as the small rounded vitrified lump on one of the lid fragments (bottom).

Sub-type **C3** crucibles also varied considerably in size but were, for the most part, not as small as C2 and not as large as C3. They range in size from 65-75mm in external height, 5-25mm in wall thickness, 48-103mm in internal chamber diameter and 50-55mm in internal chamber height. None of the larger fragments were well preserved so their external height and internal chamber height range are likely to have been bigger. They share many of the morphological characteristics of the other two sub-types but differ in that they have flat bases and domed lids (Figure 6.40). However, some of the smaller examples may have slightly convex bases. None of the domed lids have tong-marks and none show any signs of having had perforations except one example from PM103. This broken fragment consists of approximately half of the original lid. In its section (centre of the original lid) there is a perforation, a small vertical gash 3mm in diameter, which would have penetrated all the way through but is now partially fused.

PM75



PM75

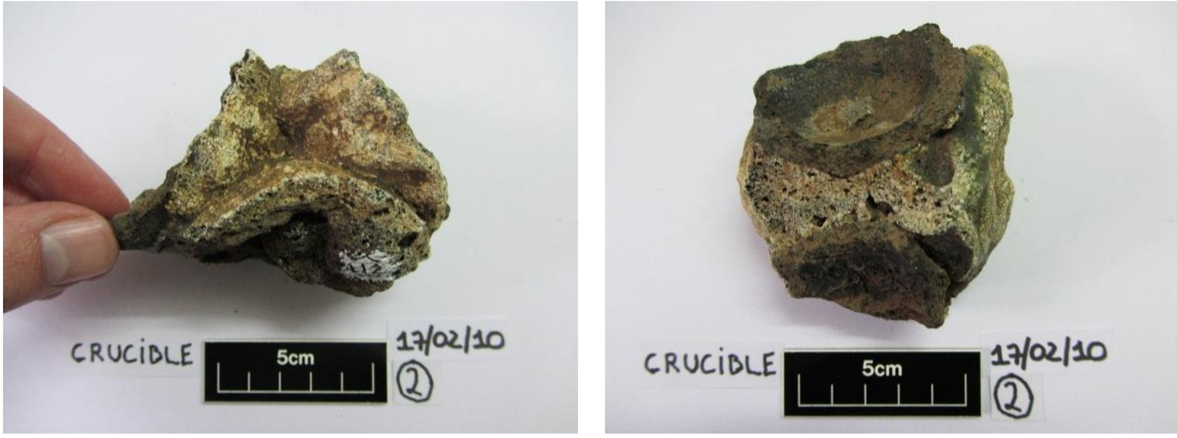


PM75

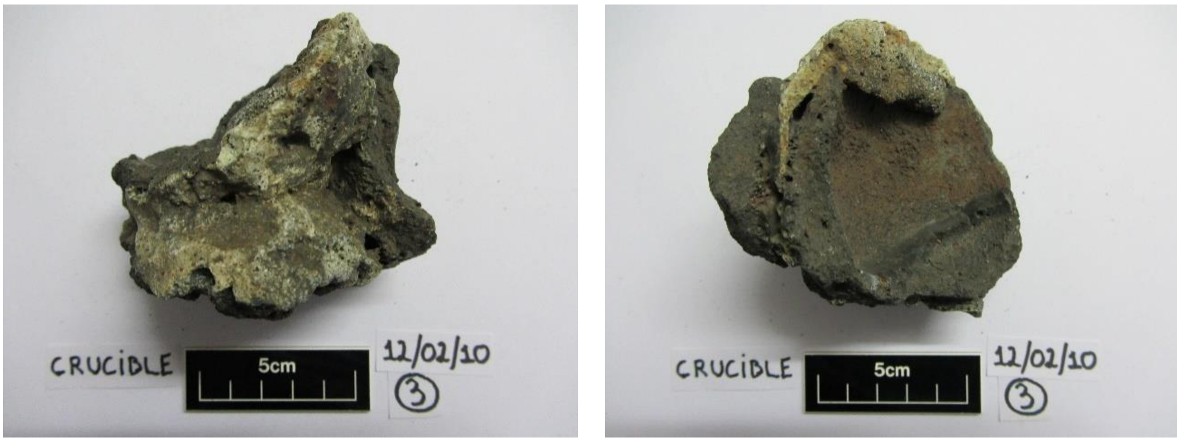
Figure 6.40 - Sub-type C3 crucible base, body and lid fragments. Note the flat base and domed lids.

There is also evidence for crucible stacking in the furnaces. Some of the small and medium fragments of all types are fused to other fragments, suggesting that more than one crucible was placed in the furnace at one time. Many of these fragments are fused body to body (Figure 6.41) suggesting that they were touching side by side but there is evidence that they were also stacked on top of one another. Examples of all three sub-types were found with base fragments fused to the top of lid fragments. In all cases, the crucibles appear to have been placed upright in the furnace but some may have moved slightly or become dislodged during firing. All fused crucibles seem to be of a similar size suggesting that crucibles were fired together in batches of the same size. It is important to note that no large C1 and C3 crucibles show evidence of stacking. They may have been put into the furnace individually and since their bases are flat with large charcoal inclusions, it is likely that they would have rested on the bottom of the furnace. Conversely, smaller examples with slightly curved undersides were probably held in the charcoal charge supported by other small crucibles.

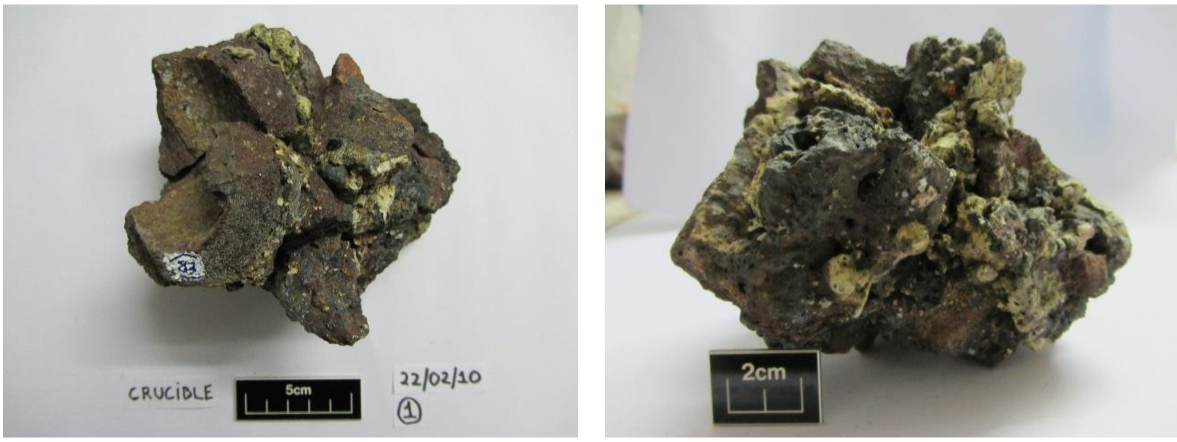
Some of the C1 fused crucibles (especially the lump from PM106) have unusual external vitrification between the crucibles. This comprises large patches of dull light grey to pale yellow material which has a medium sandpaper gritty texture (Figure 6.41). It may have been produced by the external lining of the crucibles but it resembles the light grey geological material G3 (discussed below). It is possible that some sort of material was added to the furnace such as quartz rich clay, limestone or sandstone to help keep the crucibles in place or protect them from the high temperatures. Equally possible, as proposed by Lowe (1989a, 733-4 – see chapter 2.3.3), is that the small crucibles were luted together with some sort of material to produce ingots with a coarser crystal structure.



PM88 – C2



PM75 – C3



PM106 – C1

Figure 6.41 - Fused crucible fragments. Note the grey-yellow vitrification in between the fused crucibles on the large fragment (bottom).

Two unused sub-type C1 crucible body fragments were also recovered. One large fragment from PM62 and one smaller fragment from PM65. The large fragment appears to be a quarter section of a large crucible (convex exterior shaped like a meditation bowl) while the smaller example is almost a perfect half section (Figure 6.42). Both have a similar fine, almost fibre like fabric with many very small white organic inclusions which are likely to be crushed rice husks. They are pale to dark orange in colour but the smaller fragment from PM65 has a vitrified exterior suggesting that it may have broken during the process. Both appear to have been moulded or at least finished by hand. They have large horizontal finger smears on their exterior surfaces while the insides appear to have been smoothed by hand with vertical smooth lines on the larger fragment and horizontal ones in the smaller fragment (Figure 6.42). The smaller fragment has a small central lump at the base which looks like a finger smoothed the inner part of the crucible leaving some clay material in the centre of the base (the index finger fits well against the inner wall). As it has almost the same inner diameter as other fragments from the same site, it is possible that a mould was used to shape the crucibles prior to being finished by hand. The surviving exterior vitrified surface clearly shows it to be a separate coarse quartz-rich clay (Figure 6.42). This layer has chipped off on one part showing that as the thickness of the crucible wall gets thinner towards the rim, the coarser layer gets thicker, making an even wall thickness. Some of this coarse vitrification protrudes above the rim indicating that it must have had a lid similar to other examples discussed.

PM62 – C1

PM65 – C1

Figure 6.42 - Unused sub-type C1 crucible fragments. Note the internal and external finger smoothing marks as well as the vitrified coarse layer on the smaller fragment (bottom).

6.2.7 Glassy Slags

Glassy slags form one of the minor components of the collected material, with a total of 8.8kg, accounting for less than 1% of the assemblage. The majority where broken fragments but enough original surfaces remained to enable the identification of two sub-types. The proportion of each sub-type and the number of sites on which they were found is illustrated in figure 6.43. GS1 is by far the dominant sub-type, accounting for 98% of the total weight of glassy slags, while sub-type GS2 contributes the additional 2%. GS1 slags are also more common and were found on 13 sites as opposed to 2 for the GS2 slags. The main characteristic features and size range of both glassy slag sub-types and the sites on which they were found is given in table 6.7.

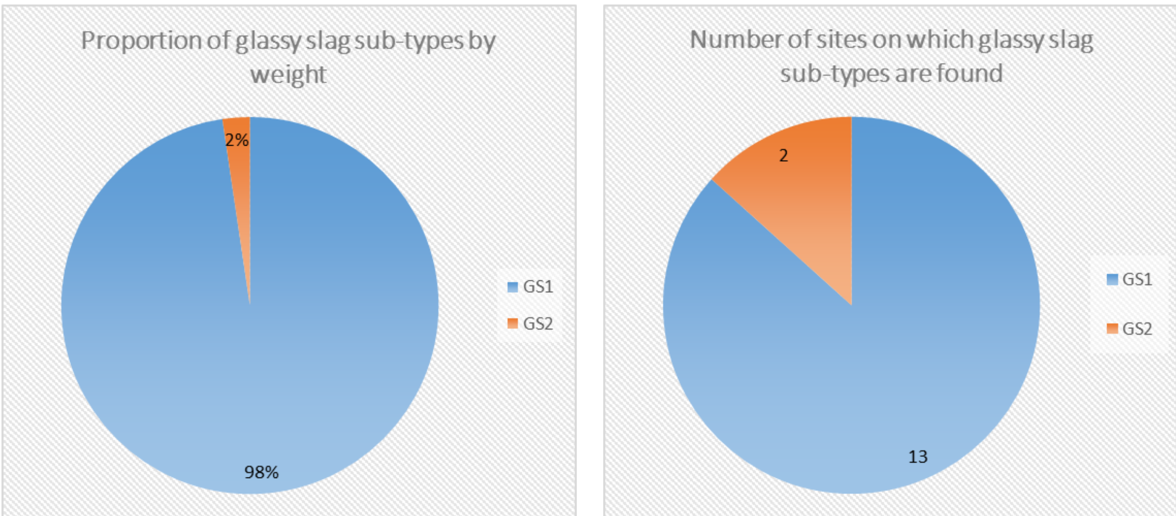


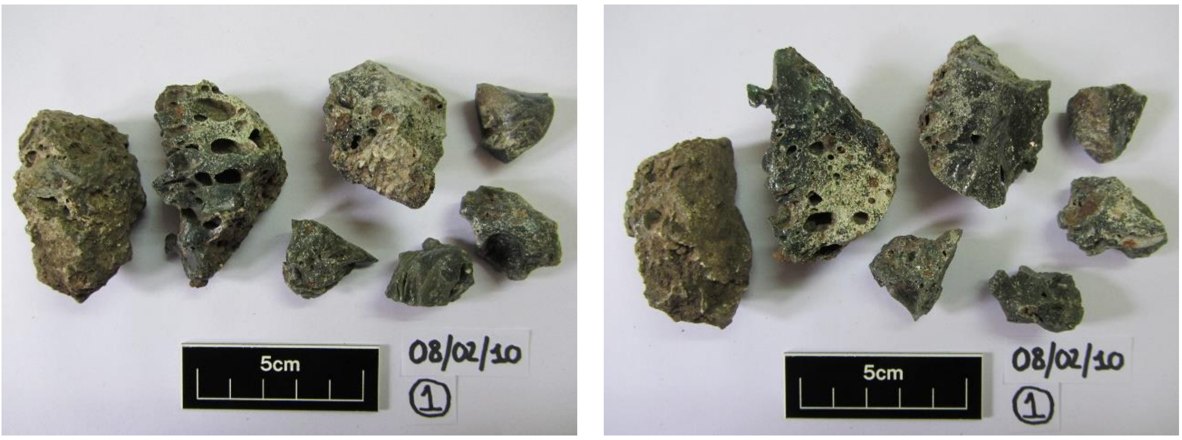
Figure 6.43 - Proportion of glassy slag sub-types by weight (9kg) (left) and number of sites on which they were found (right).

Table 6.7 - Main characteristic features, size range of each glassy slag sub-type and the sites on which they were found.

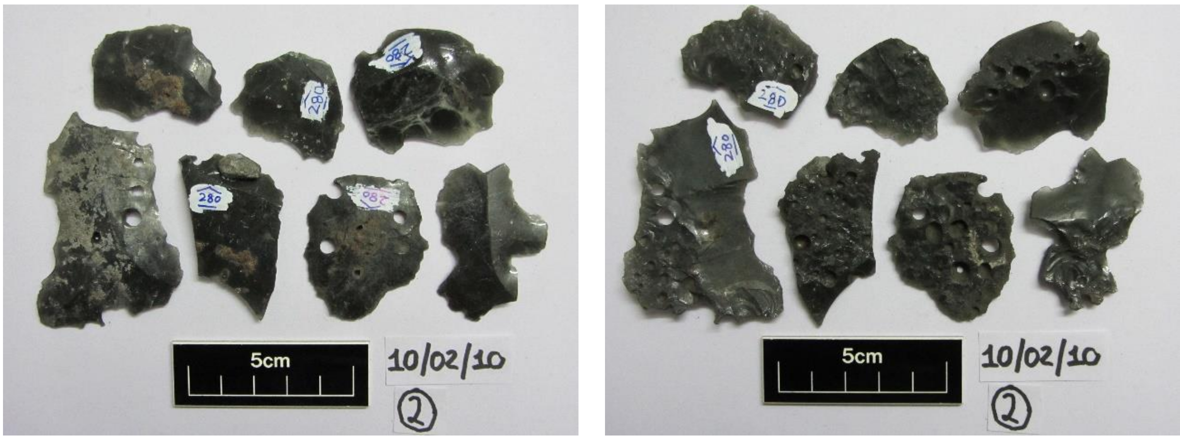
Type	Characteristic Features	Size Range	Sites Present (PM)
GS1	Green Glassy Slag – Matt pale green to dark glassy green; amorphous; rounded molten appearance; angular fractures; charcoal impressions.	Most <50mm but up to 95mm max L	18; 54; 55; 58; 60; 65; 66; 67; 88; 102; 106; 119; 128.
GS2	Black Glassy Slag – Glassy black, thin; flat profile; smooth top surface; porous bottom surface.	Up to 60mm L, 1-7mm T	62; 65.

GS1 slags are characterised by their green colouration. They are small amorphous lumps, typically <55mm in maximum length. Although all examples are broken with fractured surfaces, the majority have some intact original edges. These have small to medium well-rounded protrusions giving the impression that this material was once molten. Their colour ranges from pale green to shiny dark glassy green (Figure 6.44). In some instances, especially on larger examples, dull whitish-yellowy-grey patches are present. These areas are medium sandpaper-rough in texture and appear to be the same material as they are well fused with a clear colour transition from dull whitish-grey to dull pale green and glassy dark green (Figure 6.44). The green glassy slag is almost certainly the more vitrified parts of this material, which otherwise resembles limestone or sandstone. Along with rounded features, charcoal impressions and voids up to 50mm in size, are present on many examples. This supports the idea that this material was molten and a waste product of a metallurgical process. In general, the green glassy parts are very solid with few spherical voids, <2mm up to 8mm in size, while the whitish-grey areas are more porous with many spherical voids up to 22mm in size (Figure 6.44).

GS2 slags are diagnostic due to their very thin profiles and shiny translucent black colour. All examples are broken along most of their edges but their top and bottom surfaces remain intact. They are up to 66mm in maximum length and range in thickness from 1mm to 7mm. Most have one smooth and shiny, slightly convex side and a flat, slightly rougher, porous reverse side with spherical voids, ranging in size from 1-6mm (Figure 6.44). These are probably fragments of the black glassy slag layer that formed above the ingot, as they resemble the material of slaggy fins adhering to the internal crucible walls (see chapter 6.2.6). Indeed, a few have convex edges with imprints of the crucible wall clay fabric. The smooth, slightly convex side is likely to have been the top of the glass layer with the porous, flat side being the underside which would have been in contact with the ingot. Of particular interest is the uneven thickness of some fragments suggesting that the slag solidified at an angle. It is possible that some crucibles may have moved during firing. Small, corroded, magnetic metallic prills also adhere to the top surface of some fragments, similar to the prills found in the interiors of crucibles.



PM55 – GS1

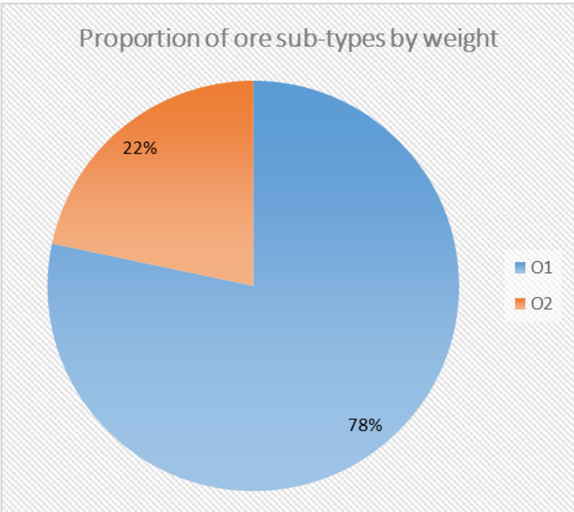


PM65 – GS2

Figure 6.44 - Glassy slag sub-types GS1 (top) and GS2 (bottom). Note the colour variation from grey to glassy green on the GS1 fragments (top) and the bulbous top side and flat porous underside of the GS2 fragments (bottom).

6.2.8 Ores

A significant quantity of ore lumps and fragments were collected, totalling 34.3kg and accounting for approximately 2% of the entire assemblage. Two main sub-types of ore were identified. The proportion of each sub-type and the number of sites on which they were found is illustrated in figure 6.45. O1 is the dominant sub-type, accounting for 78% of their total weight, while sub-type O2 contributes 22%. O1 ores are also much more common, being found on 32 sites while the O2 ores were collected from 7 sites. The main characteristic features and size range of each ore sub-type as well as the sites on which they were found is given in table 6.8.



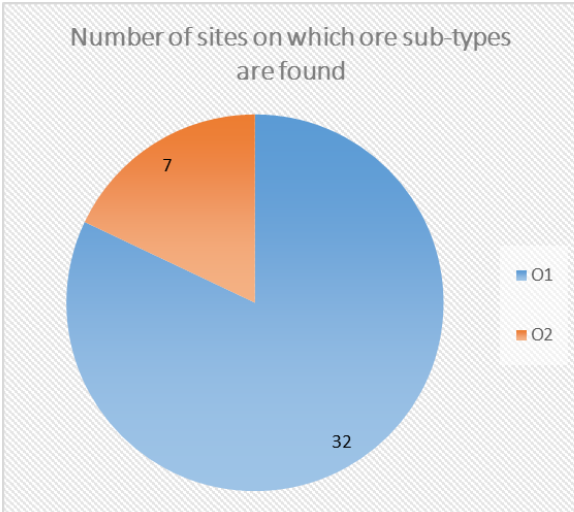


Figure 6.45 - Proportion of ore sub-types by weight (34kg) (left) and number of sites on which they were found (right).

Table 6.8 - Main characteristic features, size range of each ore sub-type and the sites on which they were found.

Type	Characteristic Features	Size Range	Sites Present (PM)
O1	Magnetic dense pieces often with black bands; probably magnetite.	<10-173mm max L	5; 6; 8; 9; 13; 14; 17; 20; 24; 27; 28; 29; 31; 34; 35; 38; 57; 58; 73; 84; 94; 98; 100; 108; 110; 112; 115; 122; 128; 131; 134; 136.
O2	Non-magnetic dense pieces; probably hematite or laterite.	31-141mm max L	12; 34; 54; 59; 74; 110; 114.

Ore sub-type **O1** range in size from <10mm to 173mm in maximum length. They vary in colour from dark brownish-red, yellowy-orangey-brown, dark brown, dark grey to black. The majority have smooth to low-rough surfaces and have rounded abraded edges. Very few have sharp angular appearances. The majority also have parallel black bands or veins of different thicknesses running through them (Figure 6.46). These are very magnetic suggesting that they contain greater iron concentrations. All examples of this type are magnetic indicating that they are banded magnetite. Their magnetism varies considerably suggesting that many are of low grade. The most magnetic examples are usually quite small in size, homogenous and fully black in colour. They appear to be the same material as the black bands found on the other pieces of this type.

The second sub-type, **O2**, consists of non-magnetic undiagnostic dense fragments. They are likely to be hematite or lateritic in origin but this has not been verified. The majority are angular with broken edges. They vary in size from 31mm to 141mm in maximum length and also vary in shades of dark brownish-red and yellowy-orangey-brown as well as different shades of grey. Most are solid with no voids but a few have very few spherical or globular voids. Their surfaces are usually flat and smooth to low-rough in texture (Figure 6.46).

PM14 – O1

PM12 – O2

Figure 6.46 - Ore sub-types O1 (top) and O2 (bottom). Note the darker parallel bands or more iron rich material on the O1 example (top).

6.2.9 Geological

A variety of geological material totalling 40.3kg was collected, accounting for approximately 2% of the entire assemblage. These were often mixed with technological debris suggesting a possible association with metallurgical activities. There was significant variation in morphological form and material type enabling the identification of six sub-types. Although many may have been associated with the metallurgical activities recorded, a few seem unlikely (G4 and G5) and will not be described in detail here. Refer to appendix C.9 for more information. The proportion of each sub-type and the number of sites on which they were found is illustrated in figure 6.47. G1 is the dominant sub-type, accounting for 54% while G6 accounts for 26% and the others for less than 8% individually. G1 and G2 were the most common, found on 5 and 6 sites respectively while the others came from 3 or less sites. The main characteristic features and size ranges of all geological sub-types and the sites on which they were found is given in table 6.9.

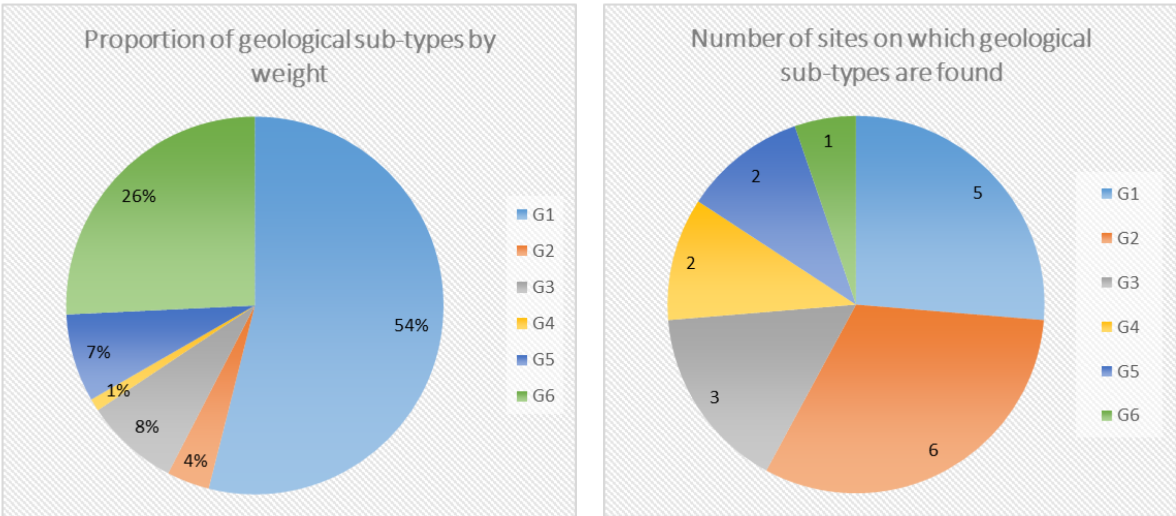


Figure 6.47 - Proportion of geological sub-types by weight (40kg) (left) and number of sites on which they were found (right).

Table 6.9 - Main characteristic features, size range of each geological sub-type and the sites on which they were found.

Type	Characteristic Features	Size Range (LxWxT)	Sites Present (PM)
G1	Large stones surrounded by coarse clay with one vitrified side. Quartzite/granite.	132x79x32mm to 236x187x80mm	24; 26; 34; 35; 84.
G2	Small amorphous complete bulbous limetone(?) pieces. Limestone.	42x30x12mm to 100mm max L	10; 11; 47; 88; 90; 97.
G3	Molten material (limestone?) with some porosity and lots of charcoal impressions. Limestone.	<70mm to 188x177x47mm	75; 102; 103.
G4	Potential ornamental shaped stone fragments.	54x31x5mm to 96x58x53mm	85; 90.
G5	Angular rocks (granite/quartzite); no evidence of having been burnt or used in metallurgical processes. Granite/quartzite.	122x83x68mm and 226x80x90mm	58; 133.
G6	Single granite furnace base with central depression and vitrified clay within this depression. Granite.	315x214x115mm	18.

G1 materials consist of large quartzite or granite rocks. These stones were probably part of furnace or hearth structures as they have adhering reduced or vitrified clay. All seem to be intact and range in size from 132x79x32mm to 236x187x80mm. They vary in colour from brownish-orange or orangey-brown to shades of mid-dark grey. All have one fully vitrified side composed of a thin coating (<10mm) of vitrified clay which sometimes extends beyond the edge of the stones (Figure 6.48). The vitrification is dark grey to black in colour, sometimes with dark brownish-red patches. It tends to be rough and uneven with small, sharp, broken protrusions of material (Figure 6.48). In some cases, charcoal impressions (up to 40mm) are noticeable but these remain few. The vitrification in some parts is flatter and smoother. There may also be a thin layer of slag on some examples. The vitrified surfaces have some porosity with spherical and irregular voids, up to 16mm. The other surfaces are bare, with no adhering clay or vitrification. It is possible that the clay broke off after deposition but they may also have protruded from the furnace wall. Most examples have adhering dark grey reduced clay on their sides (Figure 6.48). This clay is mostly coarse to very coarse, dominated by quartz crystals up to 10mm. Two examples appear to have thin layers of slag or vitrification on one edge which extends to the back (non-vitrified side) suggesting that they may have formed part of the furnace base (Figure 6.48).

PM24 – G1

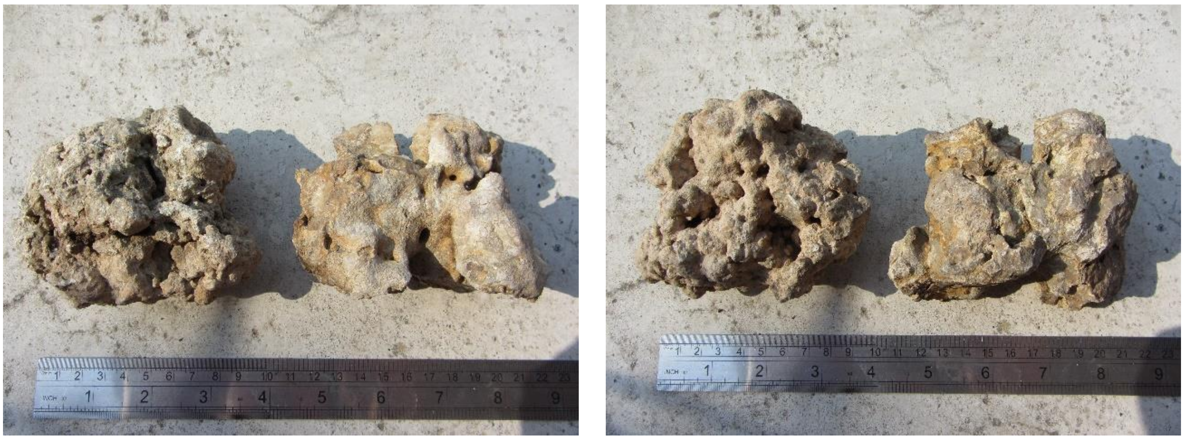
PM24 – G1

Figure 6.48 - Geological sub-types G1. Note the vitrified sides and adhering reduced clay on the reverse sides as well as the remains of slag noticeable on the bottom fragment.

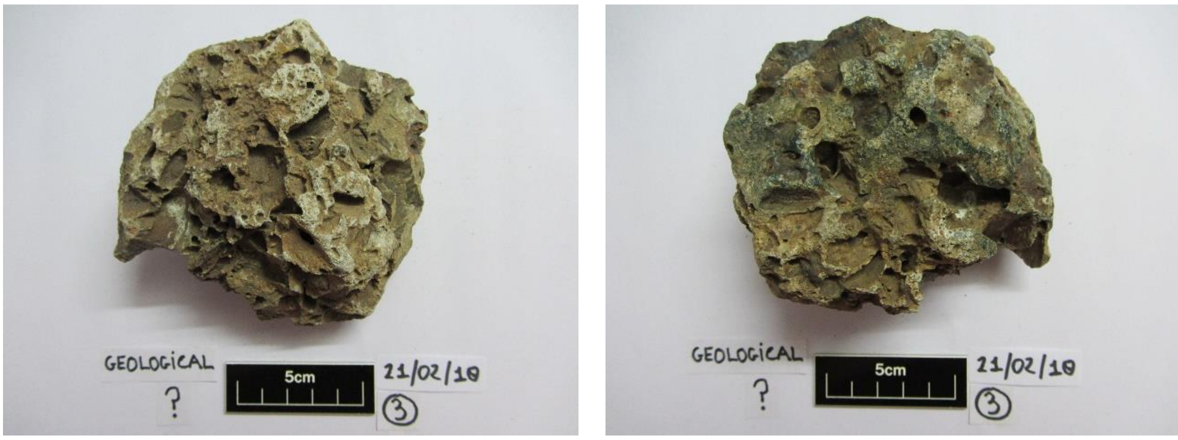
G2 material comprises small, amorphous, complete nodules of limestone. They range in size from 42mm to 100mm in maximum length. They are bulbous with rounded, smooth, small to medium projections and vary in shades of greyish-white with pale yellow and brown patches (Figure 6.49). The grain appears to be fine and the surfaces are smooth to low-rough (sandy/chalky texture). Most are solid with no to very little porosity. None show any signs of having been burnt and there is no evidence to suggest that they were used in metallurgical processes. However, the addition of limestone as a flux in the smelting process has been reported in Indian ethnographic studies (Neogi pers. comm., 2015) and witnessed by the author in 2013 while investigating iron smelting in the Azur tribe of Jharkhand, India. There, small nodules of limestone were selected, crushed and added to the iron ore charge.

Sub-type **G3** are light to mid grey, vitrified broken fragments. Positively identifying what they are is difficult but sand/limestone or vitrified coarse ceramic seems the most probable. They are generally amorphous in shape, up to 188mm in maximum length and molten in appearance with rounded features. All fragments are dominated by charcoal impressions (up to 30mm) and are porous with many spherical or globular voids varying in size from <1mm to 10mm (Figure 6.49). Some examples have small dark glassy green or pale green patches similar to the GS1 fragments discussed above. In some instances, original surfaces seem to be intact, smoother and more rounded with a texture approaching that of fine limestone. Fresh breaks on some of the smaller fragments reveal partially melted quartz crystals indicating that these may be heavily vitrified furnace lining or perhaps material added as flux.

Of particular interest are three larger fragments. One of these has several oxidised metallic (magnetic) prills, <7mm in size, embedded in its surface. These are similar to those found within crucible fragments. Another example has vitrified coarse to very coarse clay evenly fused on one of its sides, further reinforcing the idea that some of these fragments may have been furnace lining. However, the most interesting is from PM75. It consists of a large slab of similar material 188x177x47mm in size with similar surface texture, porosity and charcoal impressions or voids. There are two crucible fragments on one side and another on the other side (Figure 6.49). These appear to be side or body sherds and their presence on both sides suggests that it was standing upright in the furnace and unlikely to have been a base (unless it was reused and the crucibles fell onto their sides). In addition, one large metallic prill and several small (<13mm) reduced sandy clay inclusions are also embedded in its surface. Its function is unknown but it was clearly part of the crucible steel manufacturing process.



PM11 – G2



PM102 – G3

PM75 – G3

Figure 6.49 - Geological sub-types G2 (top) and G3 (centre and bottom). Note the crucible fragments adhering to the G3 example (bottom).

Geological sub-type **G4** are pieces of ornamental shaped stones usually found on historic sites while sub-type **G5** are larger angular natural granite/quartzite rocks. None of these appear to have been connected to the metallurgical activities and will not be discussed here. Refer to appendix C.9 for detailed descriptions.

One large geological granite or quartzite fragment was collected and constitutes sub-type **G6**. It is 315x214x115mm in size, semi-circle in plan with a central depression (Figure 6.50). It appears to be a fragment (almost half) of a round furnace base, as the edges appear to have been broken. The depression is covered with a slaggy ceramic vitrification. This vitrification is black but covered in brown staining. It is smooth to the touch but knobbly with distinct vertical flows running down the edges of the depression (Figure 6.50). The vitrification extends beyond the granite at the base of this central depression suggesting that there must have been a hole. The periphery of the stone consists of a flat platform approximately 80mm in width (Figure 6.50). This platform has brownish-yellowy-orange staining (the colour of dried clay) suggesting that the furnace wall was built on top. In support of this are clay lining fragments from the same site which match the curvature and thickness of the platform (Figure 6.50). Small surface pitting suggests that the stone was intentionally shaped. However, it cannot be ascertained if it was shaped for its metallurgical use or recycled, for example, an old quern (which it resembles).

PM18 – G6

Figure 6.50 - Large geological fragment G6. Note the heavy vitrification present in the central depression and the perfect curvature and thickness match of a furnace wall section found on the same site.

6.2.10 Iron

A small number of iron lumps and fragments were found totalling 4.4kg and accounting for less than 1% of the entire assemblage. These iron lumps and artefacts varied in morphology and four sub-types to be identified. The proportion of each sub-type and the number of sites on which they were found is illustrated in figure 6.51. The dominant sub-types are I2 and I3 which account for 34% and 44% of the total weight respectively and are found on the most sites, 16 for I2 and 8 for I3. Both I1 and I2 sub-types contribute 18% and 4% respectively and were found on 5 or less sites. The main characteristic features and size range of each iron sub-type as well as the sites on which they were found is given in table 6.10.

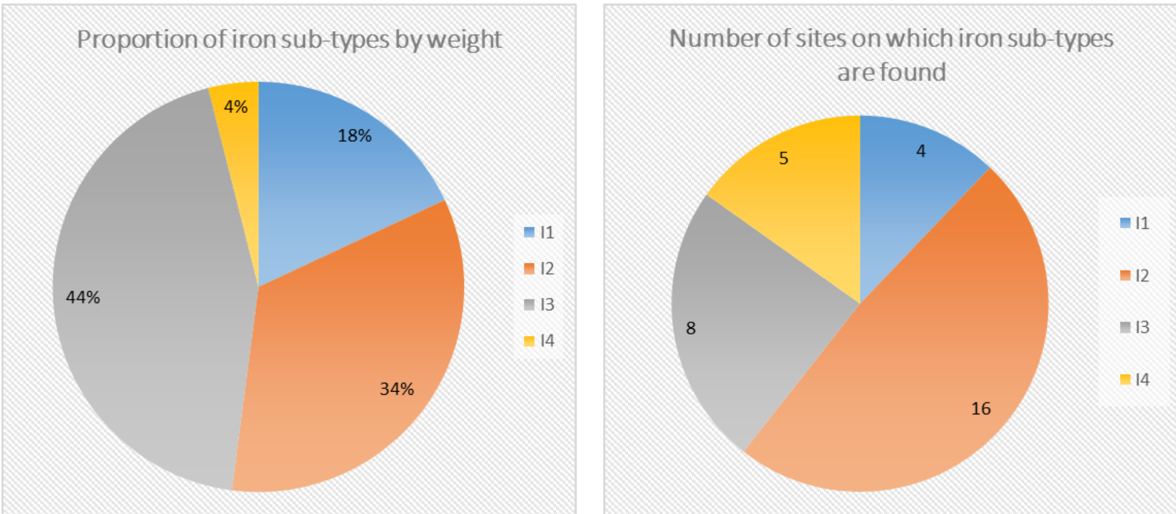


Figure 6.51 - Proportion of iron sub-types by weight (4kg) (left) and number of sites on which they were found (right).

Table 6.10 - Main characteristic features, size range of each iron sub-type and the sites on which they were found.

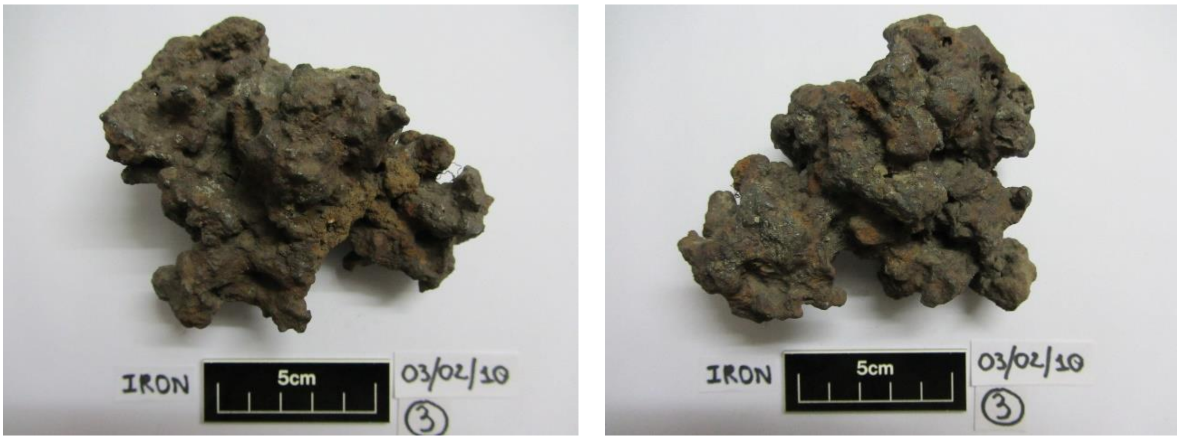
Type	Characteristic Features	Size Range (LxWxT)	Sites Present (PM)
I1	Dendritic/coral iron formation, complete pieces. High magnetism.	47-105mm max L	39; 80; 82; 112.
I2	Amorphous, dense, highly magnetic lumps.	Up to 83mm, most <40mm	3; 30; 38; 45; 74; 79; 102; 116; 119; 125; 128; 130; 131; 132; 133; 134.
I3	Iron rich slag fragments. Low to high magnetism.	Up to 121mm, most <80mm	49; 63; 74; 115; 116; 118; 119; 120; 134.
I4	Iron artefacts. High magnetism.	Various	59; 74; 83; 118; 119.

Sub-type **I1** constitutes of small, complete dendritic iron lumps (Figure 6.52). They are amorphous in shape and range in size from 47mm to 105mm in maximum length. They are also very dense and highly magnetic suggesting that they are mostly composed of metallic iron. They are dark grey in colour but dominated by patches varying in shades of dark red and yellowy-orangey-brown. This is likely the result of surface oxidisation or soil staining. Most of these iron pieces appear to be covered in a thin layer or coating of dark grey slag which probably protected them from any heavier oxidisation (corrosion) damage (Figure 6.52). The surfaces are medium rough to rough in texture with very small sharp protrusions of material. Angular gaps between the dendritic branches as well as faint charcoal imprints suggests that they formed and solidified around the charcoal charge inside the furnace. They are undoubtedly partially formed iron 'bloom' fragments isolated from the main iron consolidation or detached pieces from its extremities.

I2 iron lumps are the most common. They are small, amorphous in shape, dense and medium to highly magnetic. The majority are <40mm in maximum length but there are a few examples as large as 83mm. All lumps appear complete and solid with no surface voids but high surface corrosion makes it difficult to ascertain (Figure 6.52). They are dark grey with varying shades of dark reddish-yellowy-orangey-brown corrosion. Indeed, several fragments are fully corroded with cracked surfaces (Figure 6.52). Most surfaces are low to medium rough with very small rounded projections but in some instances there are very small to small sharper protrusions making them uneven and rougher to the touch. Some examples had interesting features. A few had one very flat side suggesting that they may have been smithed. Small fragments of iron could have broken off larger blooms during refining. In support of this are two lumps, one with very small quartz grains (<1mm) and another with a spherical prill adhering to its surface. Quartz may be evidence for sand flux in the smithing process while the prill is likely to be spherical hammerscale. Hence, it is possible that some fragments were discarded during refining.

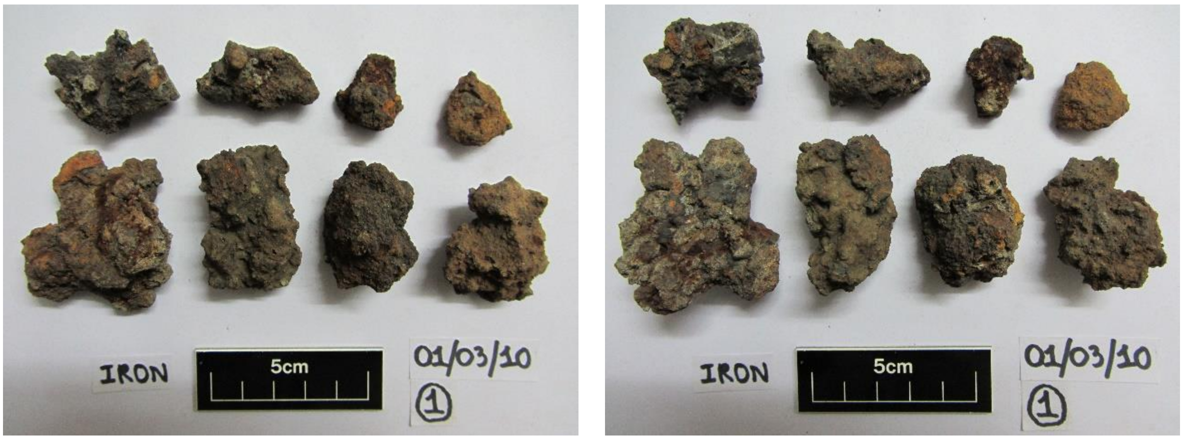
Sub-type **I3** are iron rich slag fragments. These are similar to many of the slag types described in chapter 6.2.2 but differ in that they are fully or partially magnetic, suggesting a high iron content. Most are broken, amorphous in shape and <80mm in size. The intact surfaces are mid to rough in texture and typical of slag with uneven, well-rounded projections of material (Figure 6.52). Many have charcoal imprints on their surfaces. The broken surfaces are usually rougher in texture with sharp projections. The majority are solid but some do have a few small spherical and globular voids, <10mm in size. They are dark grey or dark greyish-blue in colour with patches varying in shades of dark red and orangey-yellowy-brown. Most fragments are highly magnetic or have highly magnetic patches which tend to coincide with these coloured patches.

Sub-type **I4** consists of a number of iron artefacts in the assemblage. These will not be discussed here as they are unlikely to have been associated with the metallurgical activities. Refer to appendix C.10 for detailed descriptions.



PM39 – I1

PM74 – I2



PM74 – I3

Figure 6.52 - Iron sub-types I1 (top), I2 (centre) and I3 (bottom). Note the dendritic or coral iron nature of the I1 lump (top).

6.3 Summary

A total of 1610.3kg of technological waste was sampled from 114 sites. This material was visually analysed enabling the identification and creation of 56 material sub-types. The majority of the assemblage comprises tap (29%) and furnace (37%) slags, as well as furnace wall remnants (18%). Smithing slags, tuyeres, crucibles, glassy slags, ores, geological and iron are all minority components, equating to 6% or less individually. Unsurprisingly, tap slags, furnace slags and furnace walls were also the most common, occurring on 87-91% of all the metallurgical sites recorded. Tuyeres were the next most common, found on 64% of the metallurgical sites. This shows an overwhelming domination of iron smelting technologies in the region, with crucible fragments only recovered from 22% of the metallurgical sites. It is also apparent that within these main material groups there are dominant sub-types of material. For example, TS1, FS1, FS1.2, FS2.1, FS5, FW1, FWND2, FWND3 and T2 occur on the most sites and comprise the majority of tap slag, furnace slag, furnace wall and tuyere remains. The significance of this will be assessed in the following chapters.

The prevalence of certain materials as well as their morphological traits reveal a lot about the metallurgical practices in the region. As a whole, the dominant technology was smelting in small, slag tapping shaft furnaces. The presence of partially formed 'bloom' fragments (I1) indicates that iron was made by the solid state reduction process, and smithing waste (including smithing flats) suggests that, at least on some sites, they were refined into consolidated iron lumps or bars. The overwhelming presence of banded magnetite ore collected also indicates that this was the main ore of choice for smelting in this region. Of further significance, is the identification of three different crucible types. They vary only in minor morphological traits, such as lid or base shape and general size ranges. There are no major variations which would point to different technological origins or methods of manufacture. Indeed, the fabrics and general construction methods appear identical in all. Nevertheless, the difference in shape may be significant.

The visual examination of the material has already revealed many important aspects of past metallurgical activities in Telangana. The material will now be assessed in more detail to elucidate technological variation specifics at site and inter-site level. This will involve assessing trends such as identifying the types of materials that occur together to achieve greater resolution of technological types and their distribution.

7 Technological Repertoires

From the detailed analysis of the waste assemblages in chapter 6, typologies were defined of all the major classes of material. It is now important to assess whether technological trends can be defined from the distribution of these typologies. By identifying which materials preferentially occur on the same sites it is possible to ascertain the types of metallurgical activities that once operated. The methods used to give technological resolution and the limitations of the dataset are discussed in chapter 4.2.3, while the presence (in weight) of material sub-types by site are given in appendix B. This chapter will examine the interrelationships between material types, sites and technologies.

Technological variation was assessed by the occurrence and co-occurrence of material types on sites. These variations are reported here as technological groups (e.g. smelting group 1 or crucible group 1). It is important to note that these groups are not necessarily specific to individual sites or to particular geographical areas, but are groupings of associated material that can be identified as a technological variation. Indeed, some groups co-occur on the same sites suggesting technological variation at site level. The significance of this and a more detailed analysis of their spatial distribution will be assessed in a discussion later. The presence of technological groups on each site is presented in table 7.1.

It is also important to define what constitutes a 'technological variation'. Three principle technologies were defined – iron smelting, smithing and crucible steel. Variation within these three technologies was then assessed based on the morphology of the material and the preferential occurrence of certain material types together. Technological variation is a reflection of different manufacturing or operational processes, choice of materials and construction methods such as shape or design of furnaces and crucibles. It can be incremental, with minor changes due to idiosyncratic, individual or group practices, and/or consist of major, fundamental differences based on different desired outcomes such as scale of production or type of end product. In addition, variation can be due to chronological development and optimisation. However, before these variations in technology can be assessed they must first be defined. The following sections will present the technological groups identified within each technology, starting with smelting, then smithing and finally crucible steel.

Table 7.1 – Technological group presence on individual sites. Note that some groups co-occur on the same site. LOC. is location setting; Smith. is smithing; S is single find; ? is non-diagnostic; 1 is presence.

		Smelting groups														**Crucible groups**				**Smith.**
SITE	**LOC.**	**1**	**1.1**	**1?**	**2**	**2?**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**S**	**?**	**1**	**2**	**3**	**?**	
PM3	**BS**								1											
PM8	**S**		1																	
PM9	**S**			1															1	
PM10	**BS**														1					
PM11	**A**														1					
PM14	**S**			1																
PM18	**SE-A**	1															1			
PM19	**SE-A**			1													1			
PM21	**S**			1																
PM22	**S**	1	1																	
PM24	**SE-A**						1													
PM26	**S**						1													
PM27	**S**						1													
PM28	**A**							1												
PM30	**A**									1										1
PM31	**A**							1												
PM34	**S**						1													
PM35	**A**										1									1
PM38	**A**			1																1
PM39	**A**			1																
PM40	**A**	1																		
PM42	**A**			1																1
PM44	**SE-A**	1																		
PM45	**SE-BS**	1																		
PM46	**A**	1	1		1															1
PM47	**A**	1																		
PM48	**A**														1					
PM49	**SE-A**	1				1														1
PM50	**S**														1					1
PM51	**SE-A**			1																
PM52	**A**	1																		
PM54	**A**	1															1			
PM55	**A**	1	1																1	1
PM56	**F**	1												1						1
PM57	**A**			1																
PM58	**A**	1											1				1			1
PM60	**SE-A**												1			1				
PM62	**A**												1			1				1

		Smelting groups														Crucible groups				Smith.
SITE	LOC.	1	1.1	1?	2	2?	3	4	5	6	7	8	9	S	?	1	2	3	?	
PM63	A	1											1							
PM64	A	1																		
PM65	SE-BS														1	1				
PM67	SE-A														1	1				
PM69	S	1																		
PM70	A														1					
PM72	BS			1																
PM73	SE-BS		1																	
PM74	SE-A											1						1		1
PM75	A											1						1		1
PM76	A			1		1														
PM77	A	1																		
PM79	F			1	1															
PM80	F			1	1															
PM82	SE-A	1																		
PM83	SE-A			1																
PM84	SE-A	1																	1	
PM85	A	1																		
PM87	A			1															1	1
PM88	A			1													1			
PM90	A-BS														1					1
PM91	A			1															1	
PM92	BS			1																
PM93	A	1																		1
PM94	A-BS			1																
PM95	A	1																		
PM96	SE-BS														1					
PM97	A			1																
PM98	A														1					
PM99	A	1				1														
PM100	A-BS	1				1														
PM101	SE-A														1			1		1
PM102	S														1			1		1
PM103	S														1			1		
PM104	SE-A								1											1
PM106	S														1	1				
PM108	SE-BS			1																
PM110	A			1																
PM111	SE-A			1																
PM112	F	1			1															
PM113	SE-BS	1																		1
PM115	SE-A														1					
PM116	A	1				1														
PM117	A														1					1
PM118	A	1				1														
PM119	SE-BS			1													1			1

		Smelting groups														Crucible groups				Smith.
SITE	**LOC.**	**1**	**1.1**	**1?**	**2**	**2?**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**S**	**?**	**1**	**2**	**3**	**?**	
PM120	**SE**			1																1
PM123	**SE-BS**														1					
PM124	**S**			1																
PM125	**SE**	1																		
PM127	**SE-A**			1																
PM128	**A**	1	1											1			1			
PM129	**A**			1																
PM130	**A-BS**			1																
PM131	**S**	1																		
PM132	**SE-BS**	1																		
PM133	**SE-BS**														1		1			
PM134	**A**	1																		1
PM135	**A-BS**														1					
PM137	**SE-A**														1					
Total		33	6	29	4	6	4	2	2	1	1	2	4	2	20	5	8	5	5	24

7.1 Smelting Technology Groupings

As discussed and presented in chapters 5 and 6, iron smelting waste dominates the assemblage, with almost all the sites surveyed containing evidence for smelting. Given the geographical extent of the surveyed area and particularly the numerous material sub-types identified across the assemblage, variation in technology seems likely.

The most diagnostic materials from which variation in technological practices could be identified are furnace bottom slags (FS1 to FS1.6), furnace wall (FW1 to FW4) and tuyere (T1 to T4) types. The better preserved furnace slags and furnace walls also helped to estimate the size of the furnace structures. Some materials appeared to preferentially occur together enabling nine smelting groups to be identified. One major dominant smelting group (Smelting 1), with significant variants, was identified. Two other groups (Smelting 2 and 3) occur on several sites, while the remaining six groups occur on only two or less individual sites. Out of the 101 metallurgical sites surveyed, 23 have insufficient sample material or material in too poor a state of preservation to assign the smelting activities to an identified group. Nevertheless, the presence of tapped slags on all these indicates that iron smelting did occur, most likely by a slag tapping solid state reduction (bloomery type) process. A description of each smelting group will now be presented.

7.1.1 Smelting group 1

Smelting group 1 is the most dominant throughout the region. It occurs on 33 sites (Table 7.2). This group is defined by the presence of furnace lining FW1, tuyere T2 and furnace slags FS1 and FS1.1 (Table 7.2 and Figure 7.1). These materials also commonly occur with furnace slags FS2 or FS2.1 as well as furnace wall FWND3 (Table 7.2). There is also an abundance of TS1, TS1.1 and TS2 tap slag fragments.

Table 7.2 – Occurrence of material sub-types by weight (g) associated with smelting group 1 by site.

		Tap Slag			**Furnace Slag**				**Furnace Wall**		**Tuyere**
Site	**Loc.**	**TS1**	**TS1.1**	**TS2**	**FS1**	**FS1.1**	**FS2**	**FS2.1**	**FW1**	**FWND3**	**T2**
PM18	**SE-A**		5030	7330	2490		900	837	1230	1760	
PM40	**A**		1390	400		3850					57
PM44	**SE-A**	1326	4390					1532	2231	680	35
PM45	**SE-BS**	3703	2690						1853		483
PM47	**A**	13880					1150		3880	2160	81
PM54	**A**	210	3141		11814	1010	23	1140		522	197
PM56	**F**			3575	8750			210	1610	963	13990
PM58	**A**	840	961	12997		3130	388	780	2220	30	4786
PM63	**A**				10640		890		2356		633
PM64	**A**	2024	610		5269						4989
PM69	**S**	350			3120		234		370		
PM77	**A**	1370			1130	6330			340	590	1245
PM82	**SE-A**	4850	572	160					3140	750	
PM84	**SE-A**	797	1087			810			615	1782	660
PM85	**A**	1391	390			9456	440	260	390		650
PM113	**SE-BS**	18426		490					3480	730	881
PM125	**SE**	6170			5250		1230	1310	390	480	264
PM131	**S**	300				2240	551		350	260	
PM132	**SE-BS**	2640			8670	950		430	3246		1410
PM134	**A**	1400	1189	6569		1063		65	3402		2104
PM22	**S**	1207	1320		9340						49
PM55	**A**	1490		576	10550	870		1024	4071	4430	282
PM128	**A**	1562	1630		10050	110		4150	1750		2874
PM46	**A**	11889	9770		2870		230		18480	4250	1414
PM49	**SE-A**	2814	640		4239				3323		2930
PM95	**A**			1401	2470				5893		542
PM99	**A**	1395	390	2340			880	2330	3490	2040	5950
PM100	**A-BS**	14067	2580	750				3743	16135	8490	2244
PM112	**F**	6500	990	2700	13460	480			798	530	680
PM118	**A**	750	1410	863				1200	550	840	1314
PM52	**A**	1530	940						1790		187
PM93	**A**	930			2330			1010	2960		310
PM116	**A**	4798		1040	760				1150	1030	166

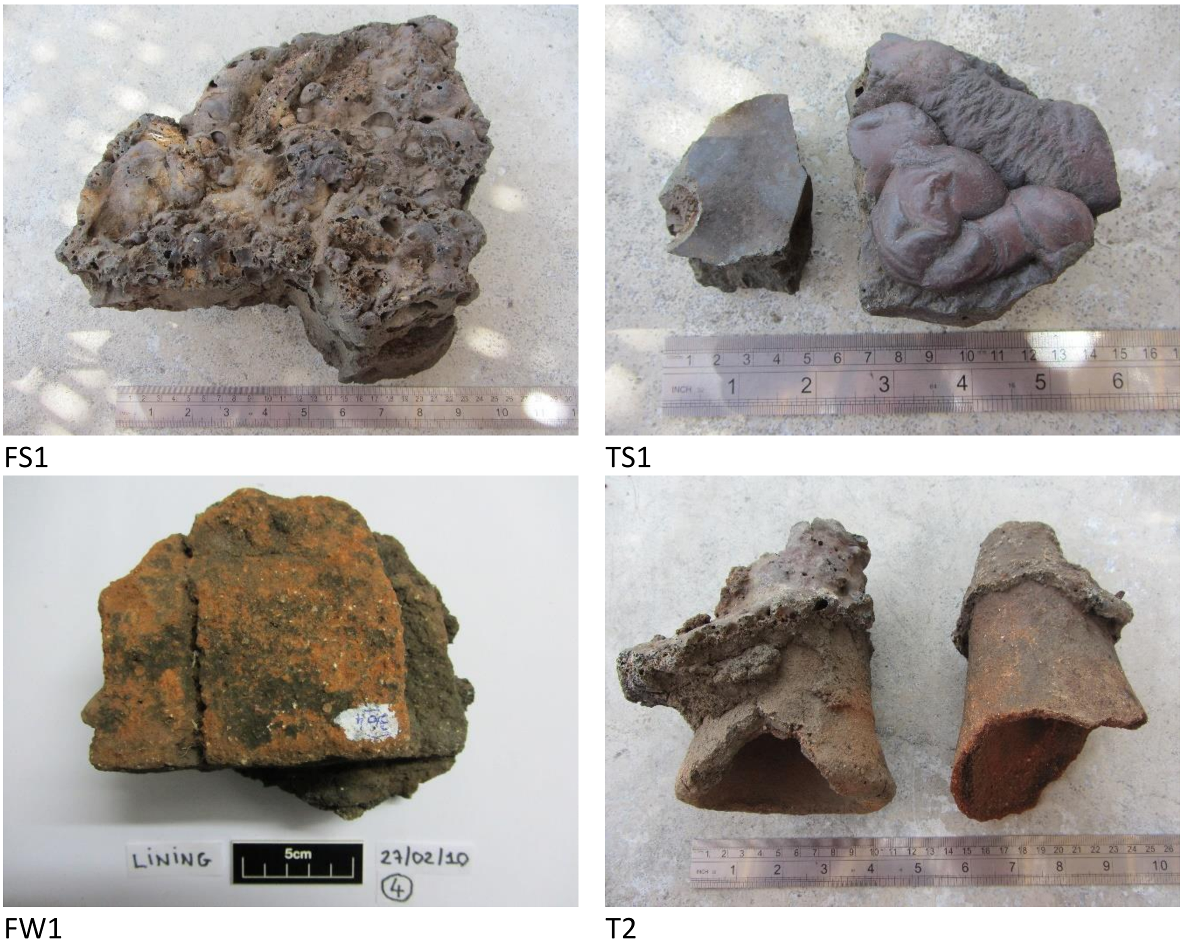


Figure 7.1 – Materials sub-types FS1, TS1, FW1 and T2 associated with smelting group 1 from PM132.

As discussed in chapter 6.2.5, there are several examples of relatively well preserved T2 tuyeres still embedded in FW1 furnace wall fragments, proving that these two types are part of the same technology. Most sites have remains of both mid-coarse quartz-tempered FW1 and organic cereal tempered FW1 fragments, suggesting that there may be some variation in furnace construction. The presence of coarse to very coarse FWND3 fragments is also interesting. It may represent a different technology which cannot be identified due to poor preservation. However, the fact that it consistently occurs with FW1 fragments suggests that it is part of the same or an associated technology. It is possible that a coarser clay was used for different parts of the furnace. It could have been used to fix the tuyeres in place and protect them from the high furnace operating temperatures. Indeed, a coarser clay was sometimes noticed on the exterior surfaces of better preserved tuyere fragments.

The better preserved remains as described in chapter 6 reveal some aspects of the furnace structure. The curvature of the wall fragments suggest that the inner diameters of the furnaces ranged from c.250-350mm, which is consistent with the diameter of the FS1 and FS1.1 plano-convex furnace bottom slags. The undersides of these cakes are covered in very small charcoal impressions suggesting that the base of the furnace was lined with charcoal fines. This would have helped to preserve the furnace, allowing easier removal of the slag and enabling the re-use of the furnace structure. In saying that, there are no visible signs of furnace relining and potential re-use in the assemblage, except one small furnace lining example from PM128 (see appendix C.4). The flat, hard baked undersides of the furnace wall bases suggests that they were built on a hard, flat surface. It is possible that they were built on a stone base but there is no clear evidence of this. The protruding vitrification on the internal surfaces of base wall fragments suggests that there was a central depression where the slag accumulated, forming the characteristic FS1 and FS1.1 furnace slag cakes.

The T2 tuyeres were positioned close to the base of the furnace wall (30-60mm) at an approximate 30-40° angle, facing down into the furnace. The best preserved examples show that their external rim were almost flush with the exterior of the furnace and protruded up to 70mm inside the furnace. Due to the relatively poor preservation of the furnace remains, it is not possible to estimate the original height of the structures. However, the presence of tapped slag on all sites suggests that these were shaft furnaces indicative of a solid state reduction slag tapping type process. The characteristic vertical, linear internal impressions also suggest that these were slab built around bundles of branches or more probably reeds, used as support (Keen 2013).

Other variations on this smelting group are likely but cannot be fully resolved due to the poor preservation of some materials. Nevertheless, it is important to discuss possible variations briefly here. Several sites (PM21, PM39, PM42, PM49, PM52, PM93, PM95, PM127 and PM134) have another sub-type of slag, a thin shaped (curved) FS5 type which may be the remains of thinner furnace bottom cakes (Figure 7.2). Most of these are broken and seem to be associated with the typical furnace wall FW1 and tuyere T2 type. Their convex undersides are usually undulated, like tap slag. If they are furnace slag cakes, it suggests that this technological variant did not use charcoal fines at the base of the furnace. It could be an intermediary technological type between smelting group 1 and smelting group 2 (discussed below). Another variation lies in the relative quantities of TS1, TS1.1 and TS2 tap slags. Some sites have a greater abundance of one of these, suggesting that there may be variation in the operating processes. On the whole, the similarity of the material on all these sites indicates that the same or very similar approach to iron smelting was in operation.


PM39 (top) (underside)


PM95 (top) (underside)

Figure 7.2 – Thin FS1 and FS5 slag cakes from PM39 and PM95.

7.1.1.1 Smelting group 1.1

One variation of smelting group 1 which is more obvious, produced smaller plano-convex furnace bottom cakes, FS1.2. These are found at sites PM8, PM22, PM46, PM55, PM73 and PM128. Although FS1.2 cakes were also recorded from several other sites, they are not as diagnostic and as well-shaped. Indeed, most appear broken and could originally have been larger. In any case, the material from the six sites identified above stand out from the rest and form smelting group 1.1. There is no evidence to suggest that the furnace structures and tuyeres used were any different from those in smelting group 1. FW1 and T2 material sub-types were found on most of these sites (Table 7.3). However, it is clear that at least on PM22, PM46, PM55 and PM128, the more common smelting group 1 technology was also in operation, making it difficult to identify material specific to smelting group 1.1. Nevertheless, PM8 and PM73 have no evidence of smelting 1 and PM73 has ceramic material of similar fabric and shape to FW1 and T2. However, on the whole the furnace remains appear to be more vitrified than on most other sites. This technology is therefore likely to be a limited variation of smelting group 1 possibly attributable to local practice.

Table 7.3 – Occurrence of material sub-types by weight (g) associated with smelting group 1.1 by site.

		Tap Slag		Furnace Slag			Furnace Wall		Tuyere
Site	**Loc.**	**TS1**	**TS1.1**	**FS1.2**	**FS2**	**FS2.1**	**FW1**	**FWND3**	**T2**
PM8	**S**	7569		12240					
PM73	**SE-BS**	2190		4130	901		8437		193
PM22	**S**	1207	1320	3880					49
PM55	**A**	1490		4120		1024	4071	4430	282
PM128	**A**	1562	1630	10050		4150	1750		2874
PM46	**A**	11889	9770	12430	230		18480	4250	1414

It is worth mentioning that even within smelting group 1.1 there is variation, with sites containing very similar slag remnants. PM8 and PM73 for example have almost identical furnace FS1.2 slags and the same for PM22 and PM46 (Figure 7.3). Both PM8 and PM73 have slags with tool marks suggesting a similar practice at both sites (Figure 7.3). The well preserved FS1.2 furnace slags at PM22 and PM46 are almost identical in shape and size, while the examples from PM8 and PM128 are slightly larger (Figure 7.3). Their undersides have large charcoal impressions suggesting that the furnace bases were not lined with charcoal fines but that the slag solidified at the base amongst the charcoal charge. The size of the cakes also suggests that the furnaces were smaller in internal diameter, around 200-250mm. It is possible that this is an intermediary technological type between smelting group 1 and smelting group 3 (discussed below).

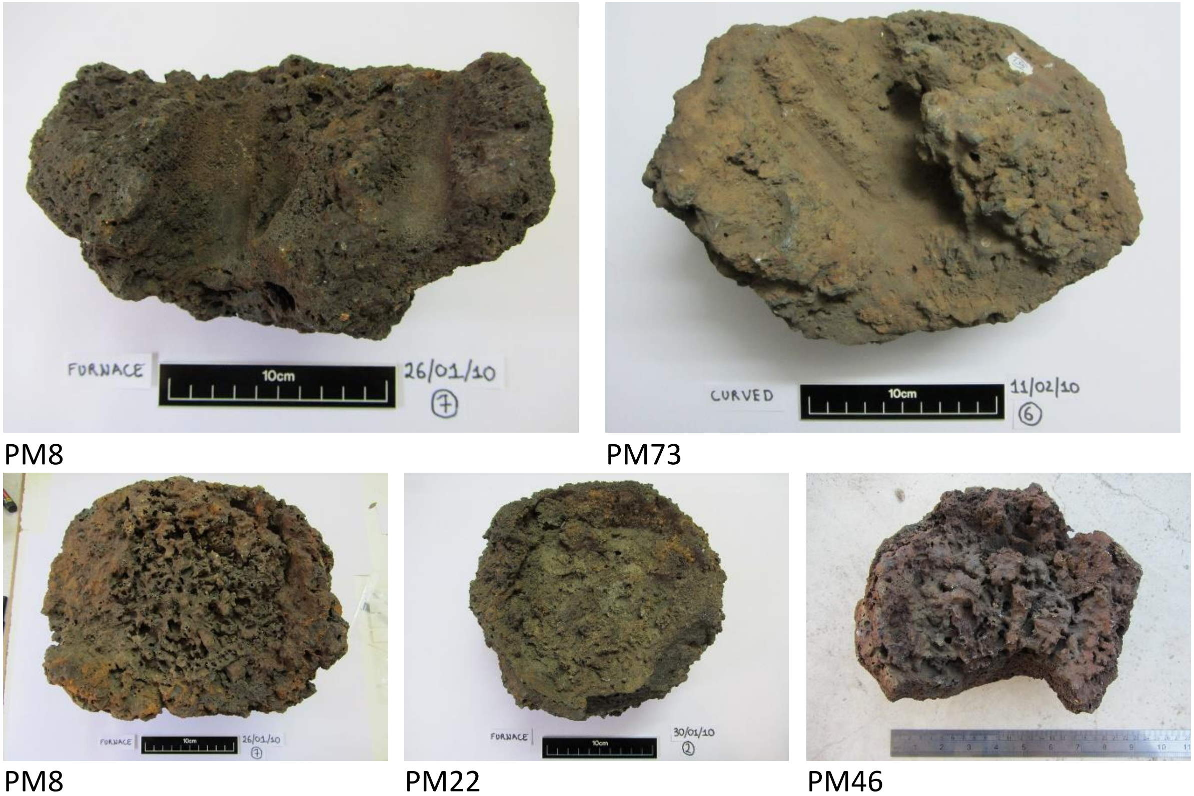


Figure 7.3 – Furnace slag FS1.2 from sites PM8, PM22, PM46 and PM73. Note the tool marks on the PM8 and PM73 furnace slags (top).

7.1.1.2 Smelting group 1 (?) - non-diagnostic

As well as the sites discussed above there are an additional 29 sites which are likely to have had a smelting group 1 operation or a variant of it. The material assemblages from PM9, PM14, PM19, PM21, PM38, PM39, PM42, PM51, PM57, PM72, PM76, PM79, PM80, PM83, PM87, PM88, PM91, PM92, PM94, PM97, PM108, PM110, PM111, PM119, PM120, PM124, PM127, PM129 and PM130 are not complete enough to permit the precise identification of smelting technology. Nevertheless, the material remnants identified are similar to those of smelting group 1 and they are probably part of this group. The remains are either poorly preserved or the main material sub-types FW1, T2, FS1 and FS1.2 which define smelting 1 groups are not all present. All the site assemblages have one or two of these characteristic types of material but not all of them. It is possible that the other material types were not seen and collected at the time of the survey as they were buried below the surface or heaped remains.

7.1.2 Smelting group 2

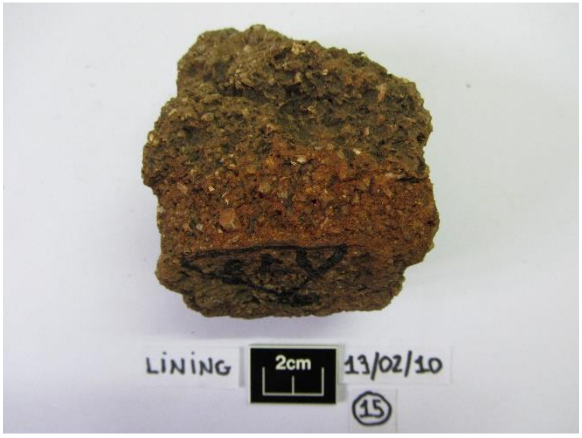
Smelting group 2 is the next most common in the region. It is distinctive on four sites (PM46, PM79, PM80 and PM112) but is also likely on a further six sites (PM49, PM76, PM99, PM100, PM116 and PM118). It is important to note that all these sites are dominated by smelting group 1 material with an abundance of FW1 and T2 fragments. This makes it difficult to detect what material types are specifically associated with smelting group 2. However, the *in situ* furnaces identified at PM79 and PM80 (discussed in chapter 5.1.4) are the best representation of this technological group. From these better preserved remains, it is possible to identify some of the main material types that characterise smelting group 2. These are thin FS1 or FS5 furnace bottom slag with a bulbous, agitated top surface, and large, thick TS1 and TS1.1 tap slag cakes (Table 7.4 and Figure 7.4). The furnace lining is coarse to very coarse in fabric, represented by non-diagnostic FWND2 and FWND3 fragments (Table 7.4 and Figure 7.4).

Table 7.4 – Occurrence of material sub-types by weight (g) associated with smelting group 2 by site.

		Tap Slag		Furnace Slag		Furnace Wall			Tuyere	
Site	**Loc.**	**TS1**	**TS1.1**	**FS1**	**FS5**	**FWND1**	**FWND2**	**FWND3**	**T2**	**T3**
PM46	**A**	11889	9770	2870	890			4250	1414	
PM79	**F**	24504	2330	6140				120	573	
PM80	**F**	7058		1290			563	760	1141	212
PM112	**F**	6500	990	13460	2120		1070	530	680	
PM49	**SE-A**	2814	640	4239	5296				2930	
PM76	**A**	13906						2150	1964	
PM99	**A**	1395	390		4640	770	1830	2040	5950	
PM100	**A-BS**	14067	2580		903	842	1388	8490	2244	
PM118	**A**	750	1410		7530		1647	840	1314	149
PM116	**A**	4798		760				1030	166	

FS1 thin (top) (underside)

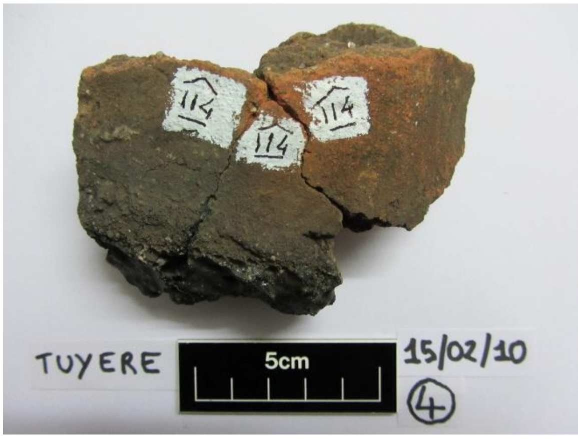
TS1 thick (top) (underside)



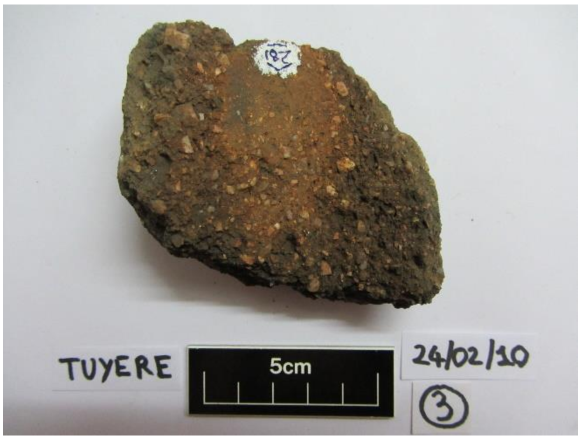
FWND3 coarse

Figure 7.4 - Materials sub-types FS1, TS1 and FWND3 associated with smelting group 2 from PM79.

As evidenced by the remains at PM79 and PM80 (chapter 5.1.4), the internal diameter of the furnaces were around 600mm. The base of the furnace had a depression dug into the ground where the slag would accumulate. The slag was then tapped from the base into a purposely dug pit or channel outside the furnace. Around the structures were stone features, including paved working floors, and upright stones which could have been part of the structure. Some of these stones are close to the furnace wall and could have supported the bellows. The height of the structures is once again impossible to determine but the shape and size of the furnaces and the waste remains are characteristic of shaft furnaces. No tuyeres were found *in situ*, so it is difficult to know what tuyere type was used. The majority of the sites have T2 tuyeres but these are likely associated with the smelting type 1 activities. Both PM80 and PM118 have small fragments of a thicker walled T3 tuyeres indicating that larger tuyeres may have been used (Figure 7.5). This would fit with the larger furnace size and coarse nature of the furnace wall fabric. The complete, large and thick tap slag run found *in situ* at PM79 suggests that slag tapping occurred in one event, perhaps towards the end of the smelt when the iron was retrieved. Indeed, all the thick tap slag cakes found on these sites are homogenous with no signs of layering which one would expect if the slag had been tapped more than once during the process.



PM80



PM118

Figure 7.5 – Tuyere T3 possibly associated with smelting group 2 from PM80 and PM118.

The remains at PM49, PM76, PM99, PM100, PM116 and PM118 are less diagnostic. Most of these sites have material types associated with smelting group 2 but in small quantities (usually one or two slag fragments). The remains are dominated by those of smelting group 1. This is indeed a problem with identifying smelting 2 remains. The coarse furnace fabric is very friable, while the thin furnace bottom slags are brittle. Both of these have a tendency to break up when handled suggesting that smelting group 2 remains were less likely to survive post depositional processes. It is possible that the technology was more widespread in the region but the remains on some sites may have deteriorated beyond recognition.

Nevertheless, the thin furnace bottom cakes and large tap slag fragments recovered on these sites suggests that smelting 2 or a variation of it was in operation. It may also be the intermediary smelting group 1 technology which produced thinner furnace slag cakes (discussed above) but the abundance of non-diagnostic coarse furnace lining material on these sites makes smelting group 2 more likely.

7.1.3 Smelting group 3

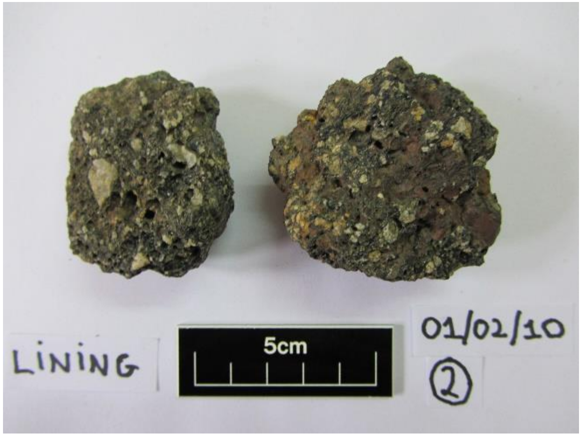
Smelting group 3 remains were found on four sites (PM24, PM26, PM27 and PM34) and do not overlap with other smelting groups. The characteristic material types which define this smelting group are FS1.2 furnace bottom slag cakes, an assortment of FS2, FS3 and FS5.1 slags and a coarse non-diagnostic furnace lining FWND1 or FWND3 (Table 7.5 and Figure 7.6). Another material sub-type exclusive to this group, is geological G1 found on three of the sites (Table 7.5 and Figure 7.6). There is also an abundance of TS1, TS1.1 and TS2 tap slag, with TS2 dominating. Both large TS2 cakes discussed in chapter 6.2.1 are of this technological type.

Table 7.5 – Occurrence of material sub-types by weight (g) associated with smelting group 3 by site.

		Tap Slag			Furnace Slag				Furnace Wall		Tuyere	Geo.
Site	**Loc.**	**TS1**	**TS1.1**	**TS2**	**FS1.2**	**FS2**	**FS3**	**FS5.1**	**FWND1**	**FWND3**	**T2**	**G1**
PM24	**SE-A**	137	2010	5251		2450	2200	4040	295	5629	190	6540
PM26	**S**	1130			3150			430		340		6390
PM27	**S**	570		4310	10310			370	210	420		
PM34	**S**	4516	1090	1208	12690	1090	550		106	1270	125	7380

G1 - external

G1 - internal



FWND3

TS2

Figure 7.6 – Material sub-types G1, FWND3 and TS2 associated with smelting group 3 at PM24.

The majority of the furnace wall remains are fragmentary and vitrified. The only exception is a large fragment of vitrified furnace wall from PM24 (Figure 7.7). It has a considerable amount of adhering slag on the interior surface and appears deformed, therefore, the furnace diameter cannot be estimated from these furnace remains. However, the presence of FS1.2 furnace slag cakes suggest that the internal diameter was around 200-250mm. The undersides of the cakes are dominated by large charcoal impressions, indicating that the slag solidified at the base of the furnace around the charcoal charge (Figure 7.7). The cakes are also thicker than the FS1.2 examples of smelting group 1.1, suggesting that the depression at the base of the furnace might have been deeper. The presence of G1 fragments with the same coarse clay adhering to their edges, is evidence that the furnace walls had large granite or quartzite stones in them. All have at least one edge without adhering clay or vitrification, indicating that they formed part of the base of the furnace, with the clay structure built on top. Very few tuyere fragments were collected from these sites but those examined appear to be of sub-type T2 with flaring rims but their poor preservation prevents definite identification. As a whole, this smelting group differs from the more common smelting group 1 but the waste material is still consistent with smelting in a slag tapping shaft furnace.

PM24 - FWND3 exterior

interior

PM27 - FS1.2 top

base

Figure 7.7 – Material sub-type FWND3 from PM24 (top) and FS1.2 from PM27 (bottom) associated with smelting group 3.

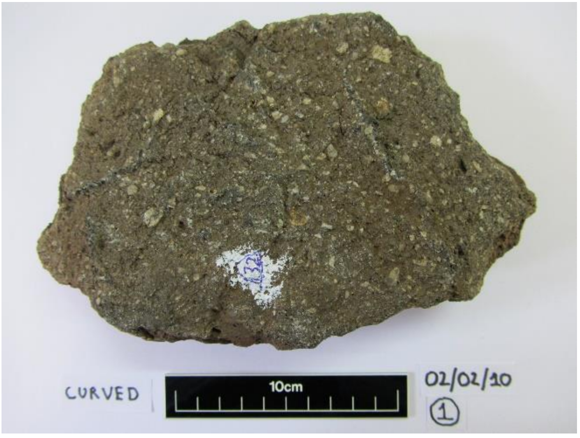
7.1.4 Smelting group 4

Smelting group 4 remains were found at PM28 and PM31. The characteristic material sub-types of this group are FS1.3 furnace slags with adhering clay and T1 tuyeres (Table 7.6 and Figure 7.8). There is also a mixture of FS5, FS5.1 and TS1.2 slags. No diagnostic furnace wall fragments were recovered but the adhering clay on the FS1.3 slags suggest that a coarse quartz-tempered fabric was used. It is possible that these remains are part of smelting group 3 but the presence of well-preserved T1 tuyeres and the lack of any diagnostic materials associated with smelting group 3 indicates a different technological practice. The FS1.3 cakes are interesting. They could be furnace bottom slag cakes which would indicate that the furnace bases were lined with clay. However, they could equally be fragments of furnace wall with a thick internal coating of slag. In either case, the preservation of the collected materials does not permit an accurate estimate of furnace size. The vitrification on the tuyeres suggests that they were placed in the furnace wall at an angle, facing down into the furnace. The added lumps of clay close to their nozzles also indicates that they were fixed in place with a similar coarse clay. On the whole, the waste is characteristic of smelting in a slag tapping shaft furnace.

Table 7.6 – Occurrence of material sub-types by weight (g) associated with smelting group 4 by site.

		Tap Slag	Furnace Slag				Fur.Wall	Tuyere
Site	**Loc.**	**TS1.2**	**FS1.3**	**FS5**	**FS5.1**	**ND**	**FWND2**	**T1**
PM28	**A**		2423	640	2260		700	2072
PM31	**A**	2440	23140			1520	430	3868

FS1.3 top



base

T1

T1

Figure 7.8 – Material sub-types FS1.3 and T1 from PM31 associated with smelting group 4.

7.1.5 Smelting group 5

Evidence for smelting group 5 was found on only two sites, PM3 and PM104. The characteristic material sub-types associated with this group are FS2.1 furnace slags, non-diagnostic FWND2 furnace wall and T1 tuyeres (Table 7.7 and Figure 7.9). Although no tap slags were recovered from PM104, TS1 and TS3 tap slags were observed and collected from PM3 (Table 7.7 and Figure 7.9).

The main feature of this technological group is the overwhelming dominance of furnace slag sub-type FS2.1, suggesting a distinct operational process. The furnace walls are not well preserved and only small mid-coarse quartz-tempered, non-diagnostic fragments were observed and recorded as FWND2. One larger fragment was recovered from PM3 with an internal coating of slag but the exterior surface is entirely abraded. No furnace bottom slags were recovered. The original size and diameter of the furnaces cannot be estimated but both sites have tuyere T1 remnants, similar to those associated with smelting group 4. It is possible that these two groups (4 and 5) are associated in some way but the dominance of FS1.2 slags and finer furnace wall fabrics suggests a different operating practice. The presence of TS3 tap slags indicates that slag was tapped from the furnace and probably channelled away in small linear ground depressions.

Table 7.7 – Occurrence of material sub-types by weight (g) associated with smelting group 5 by site.

		Tap Slag		Furnace Slag			Furnace Wall		Tuyere
Site	**Loc.**	**TS1**	**TS3**	**FS2.1**	**FS5**	**FS5.1**	**FW1**	**FWND2**	**T1**
PM3	**BS**	4706	3030	26108	5204			2471	2756
PM104	**SE-A**			2860		1100	80	810	362

FWND2

T1

FS2.1

TS1.3

Figure 7.9 - Material sub-types FWND2, T1, FS2.1 and TS1.3 from PM3 associated with smelting group 5.

7.1.6 Smelting group 6

Evidence for smelting group 6 was found on one site only, PM30. The characteristic material sub-types associated with this group are FS6 slags and FW1 furnace wall (Table 7.8 and Figure 7.10). A good proportion of the waste also included TS1, TS1.1 and TS3 tap slags. Very little material was sampled from this site and no tuyeres or furnace bottom slags were observed during the survey. This limits a more comprehensive assessment of smelting group 6. The furnace wall fragment is of a fine fabric, tempered with a type of cereal grain. The shape, thickness and fabric is consistent with FW1 furnace walls associated with smelting group 1 but its fragmentary nature limits further interpretation. The major defining characteristic of this group is the dominance of FS6 furnace slags. All furnace slag, including the shaped FS5 fragments have a fine porous consistency, honeycomb texture. Slags of this type in such abundance, have not been found on any other site suggesting that the smelting technology at PM30 was different. The presence of tap slags indicates that despite the differences in furnace slag texture, the technology was smelting in slag tapping furnaces.

Table 7.8 – Occurrence of material sub-types by weight (g) associated with smelting group 6 by site.

		Tap Slag			Furnace Slag		Fur.Wall
Site	**Loc.**	**TS1**	**TS1.1**	**TS3**	**FS5**	**FS6**	**FW1**
PM30	**A**	2330	1450	1010	1650	4390	510

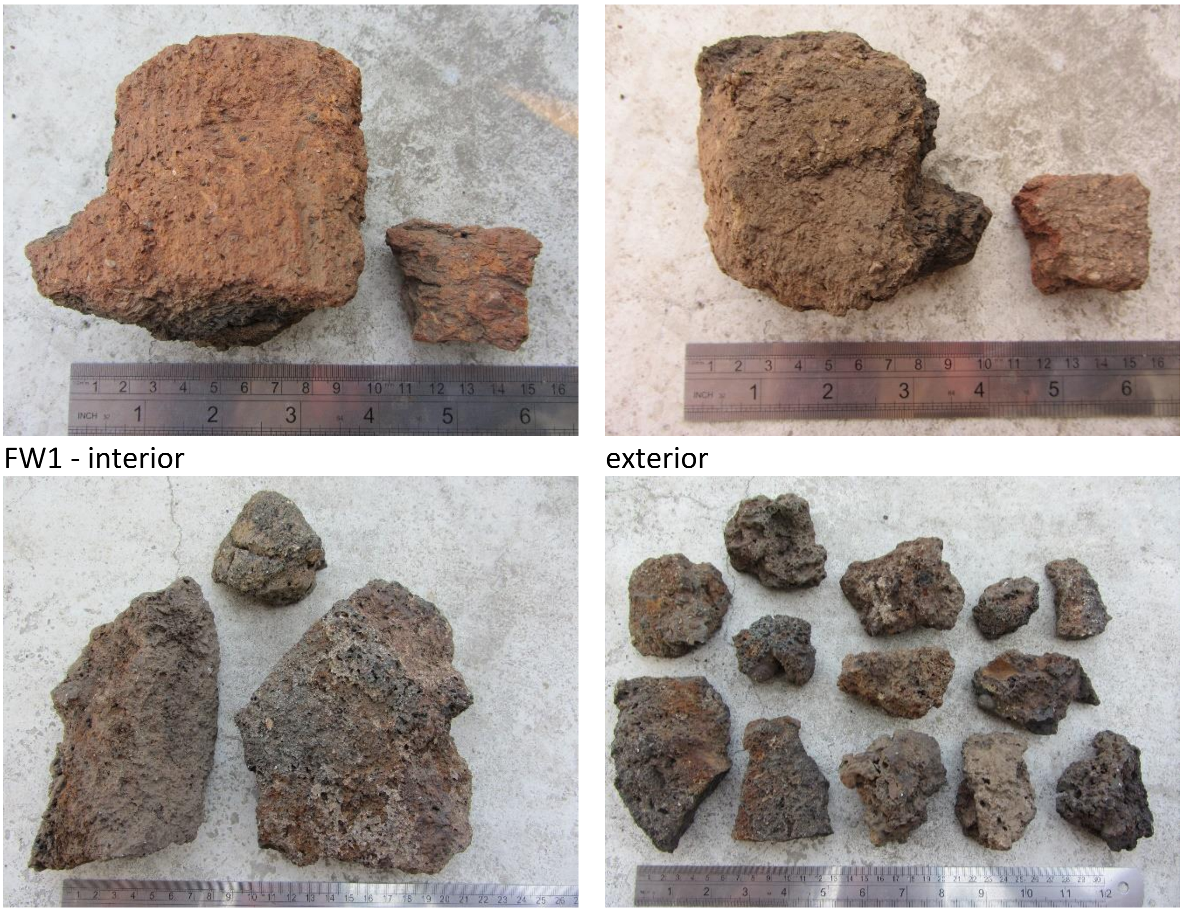


Figure 7.10 - Material sub-types FW1 and FS6 from PM30 associated with smelting group 6.

7.1.7 Smelting group 7

Smelting group 7 is also found on a single site, PM35. The remains observed at this site are the most distinct within the whole assemblage. The materials which define this technological group are FS1.5 furnace bottom slag cakes and non-diagnostic tuyeres TND3 (Table 7.9 and Figure 7.11). TS1 and TS3 tap slags were also recovered along with a furnace wall material resembling sub-type FW1.

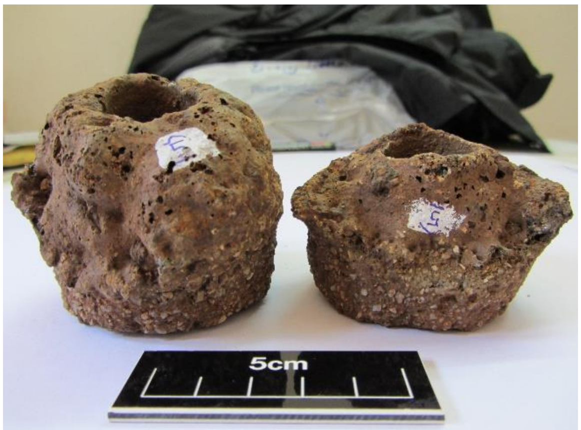
Table 7.9 – Occurrence of material sub-types by weight (g) associated with smelting group 7 by site.

		Tap Slag		Furnace Slag		Fur.Wall	Tuyere	Geo.
Site	**Loc.**	**TS1**	**TS3**	**FS1.5**	**FS5.2**	**FW1**	**TND3**	**G1**
PM35	**A**	912	213	9070	280	1380	544	460

FS1.5 top

underside

TS3



TND3

Figure 7.11 - Material sub-types FS1.5, TS3 and TND3 from PM35 associated with smelting group 7.

The furnace wall fragments are all of a fine to mid-coarse fabric with organic fibrous inclusions. The curvature of the better preserved examples indicate a furnace inner diameter between 250-280mm. This is not consistent with the smaller FS1.5 furnace bottom cakes which are <150mm in diameter. Therefore, it is likely that another technology was in operation at PM35 but the lack of any other diagnostic material prevents identification. In any case, by far the most dominant material observed on site were small FS1.5 slag cakes, which numbered in the hundreds possibly thousands. All other sub-types constituted minor components of the assemblage. A description of the cakes has already been discussed in chapter 6.2.2. Their characteristic small, plano-convex shape are distinctive and no parallels were found in the literature or in the field. They could represent a smelting technology employing a very small diameter furnace. The small quantity of tap slag observed also suggests that this was not a tapping technology.

On the other hand, they could equally be the waste of another technology. Possible explanations are primary smithing or 'bloom' refining. However, the amalgamation of small slag runs which constitutes these cakes would be unusual for smithing waste. Smithing slag tends to accumulate in a homogeneous molten pool at the base of the hearths. Furthermore, smithing waste tends to solidify within the charcoal charge, which usually leaves a greater number of charcoal impressions or voids than are present on these cakes. A different metallurgical process is clearly occurring at this site but further work including analysis of the slags is required to elucidate the nature of the operation. Future excavations could also help in its identification.

7.1.8 Smelting group 8

Smelting group 8 is a general assessment of site PM74 and to a lesser extent PM75. The remains present appear to be a variation of smelting group 1 but deserve particular mention due to the overall difference in slag and furnace wall morphology. PM74 was visited twice during the survey and is one of the sites with the most material collected. A good selection of most tap and furnace slag sub-types was collected at PM74 as well as some furnace wall and tuyere fragments (Table 7.10).

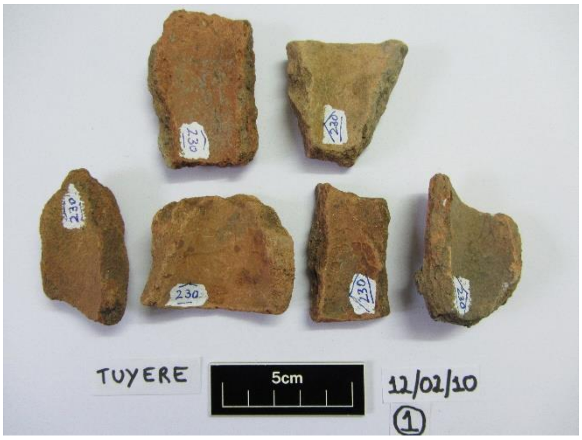
Table 7.10 – Occurrence of material sub-types by weight (g) associated with smelting group 8 by site.

		Tap Slag				Furnace Slag						Furnace Wall		Tuyere	
Site	**Loc.**	**TS1**	**TS1.2**	**TS2**	**TS3**	**FS1.1**	**FS1.2**	**FS3**	**FS4**	**FS5**	**FS5.1**	**FW1**	**FWND2**	**T2**	**T4**
PM74	**SE-A**	3379	1070	2477	2245	5330	4551	2823	1480	4327	6365	3355	6096	435	689
PM75	**A**						5550	1446		849			725		

The FW1 furnace wall fragments recovered are similar to those found on smelting group 1 sites, with comparable wall thicknesses, shape and an estimated internal diameter of around 280-360mm. However, the fabric type was not found at any other site. Most fragments are fine, silty, tempered with very few quartz grains, some fibrous organic material and small pieces of slag (Figure 7.12). Two types of tuyeres were also recovered. A T2 sub-type with flaring rim and T4 tuyeres which were only found on this site (Figure 7.12). Both types are made of a finer, siltier fabric than most tuyeres found elsewhere. It is evident that something different was occurring at PM74 and that there may have been more than one smelting technology or variant in operation.

FW1

FW1



T2

T4

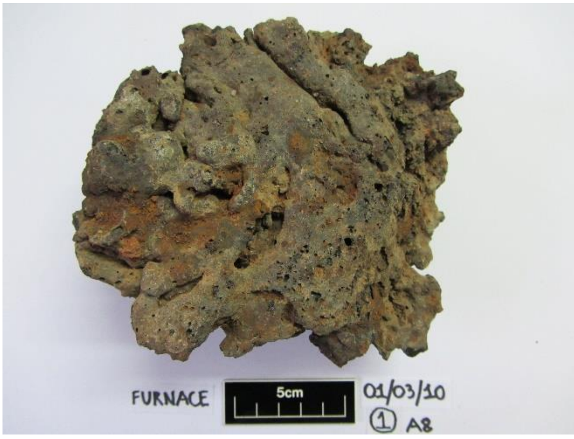
Figure 7.12 - Material sub-types FW1, T2 and T3 from PM74 associated with smelting group 8.

In addition, the slags at PM74 are more porous than most other smelting group 1 examples. They are also dominated by dark reddish-orangey-brown patches and patches varying in shades of grey (Figure 7.13). The surfaces are all gritty in texture and on the whole appear more agitated than slags found on other sites (Figure 7.13). The dominant technology is probably a variant of smelting 1 with FW1 furnace walls, T2 or T4 tuyeres and FS1.1 furnace bottom slags. Although no diagnostic ceramic material was recovered from PM75, the similarity in slag morphology and identical ceramic temper suggests that the same technology was in operation there.


FS1.1 - top


base

FS4



FS5.1

Figure 7.13 - Material sub-types FS1.1, FS4 and FS5.1 from PM74 associated with smelting group 8.

7.1.9 Smelting group 9

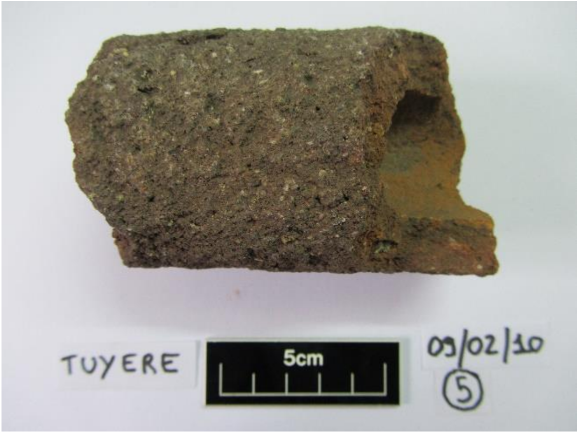
Smelting group 9 is a general assessment of the material from PM58, PM60, PM62 and PM63. Although PM58 and PM63 are dominated by smelting group 1 waste, they may also have another smelting variant. All four sites have T1 tuyeres suggesting that something different was occurring there (Table 7.11 and Figure 7.14).

Very few smelting remains were recovered from both PM60 and PM62 as they consist mostly of crucible steel remains. However, the little slag that was collected shows no major difference to the remains of the more common smelting group 1 technology. On the whole though, tap slag is dominated by the TS2 sub-type which may be significant. It is possible that a technology sharing properties of smelting groups 1, 4 and 5 was in operation. Further resolution is not helped by the poor preservation of the furnace wall fragments, which are non-diagnostic. Due to this, the smelting activities at both sites cannot be positively identified. Nevertheless, the presence of T1 tuyeres deserved mention.

Another possibility is that this type of tuyere was employed for the crucible steel activities recorded on all four sites but their presence at PM63, which has very little evidence of crucible steel production, is counter-indicative. Although the smelting activities at these sites cannot be interpreted any further, it appears that a variant of smelting groups 1, 4 and 5 was in operation, employing a T1 tuyere sub-type and producing an abundance of TS2 tap slag.

Table 7.11 – Occurrence of material sub-types by weight (g) associated with smelting group 9 by site.

		Tap Slag		**Furnace Slag**				**Furnace Wall**		**Tuyere**
Site	**Loc.**	**TS1**	**TS2**	**FS1.2**	**FS2.1**	**FS5**	**ND**	**FWND2**	**FWND3**	**T1**
PM58	**A**	840	12997	1670	780	6157		875	30	2846
PM60	**SE-A**	101	1933	1370	1272	1420	1801	3350	1975	32
PM62	**A**		3730						240	238
PM63	**A**					560		179		2243



PM62 PM63

Figure 7.14 – Material sub-types T1 from PM62 (left) and PM63 (right) associated with smelting group 9.

7.1.10 Singular Finds

Two singular finds, morphologically very distinct from the rest of the assemblage, were found at PM56 and PM128. These comprise of the large bucket shaped furnace bottom slag cake FS1.6 described in chapter 6.2.2 and the large plano-convex FS1.3 slag cake with adhering clay described in appendix C.2.4 (Figure 7.15). They are both furnace bottom slag cakes of a smelting process but their unusual shape makes them stand out within the assemblage. The FS1.6 cake could be the remains of a non-tapping smelting technology whereby the slag was allowed to collect at the base of the furnace or within a purpose-dug slag-pit. The remains of clay on the edges suggests that it solidified within a clay structure or clay lined hole. The FS1.3 cake is tear shaped, with the broken pointed end probably where slag was tapped. Clay covers the majority of the cake’s underside suggesting that the base of the ‘furnace’ was lined with coarse to very coarse quartz-tempered clay. Since both slag cakes are singular finds, it is difficult to interpret the processes which produced them any further. Both sites are dominated by remains of smelting group 1 and no other unusual material residue was found which may be associated with these singular finds.

PM128

PM56

Figure 7.15 - Material sub-types FS1.6 from PM128 (left) and FS1.3 from PM56 (right).

Irrespective of the precise identification of the processes that formed them, they prove that the metallurgical activities once in operation in the region were very complex, encompassing a variety of technologies. They also indicate that this complexity and variety is likely to be more diverse than the few smelting operations identified above.

7.1.11 Summary

The interpretation of the assemblage and identification of metallurgical groupings is limited by the original sampling methods. The lack of stratigraphic context and the mixed material assemblages sampled from the ground surface prevents the more complete resolution of technological identification. Most of the metallurgical waste observed on these sites was heaped, hence, the materials collected may only represent a fraction of what was present and future excavations may reveal more on the processes operating in the region. Nevertheless, nine smelting technological groupings or variations were identified. All of these are characteristic of the solid state reduction iron smelting process, most likely in modest-sized shaft furnaces. The majority also appear to be slag tapping processes with an abundance of tap slag identified on most sites. The only exception is perhaps smelting group 7 which could be a refining process. In any case, there is apparently no evidence for cast iron production which would be required for crucible steel manufacture via the co-fusion process (see chapter 2). Potential explanations for these smelting variations and an assessment of their spatial distribution will be discussed in a later section. Having reviewed the smelting waste it is now important to assess the smithing waste.

7.2 Smithing Technology

Clear evidence of smithing was found on 24 sites. The material mostly comprises smithing slag sub-types SS1, SS2 and SS3 described in chapter 6.2.3 (Figure 7.16). These were found on sites PM30, PM35, PM38, PM42, PM46, PM49, PM50, PM55, PM56, PM58, PM62, PM74, PM75, PM87, PM90, PM93, PM101, PM102, PM104, PM117, PM119, PM120 and PM134. Furnace wall sub-type FW4 described in chapter 6.2.4 is another material associated with smithing (Figure 7.16). A single example was found at PM113 and it is most likely a charcoal retaining wall of a smithing hearth. In addition to the more probable smithing waste outlined above, material sub-types FS1.4 and FW3 may be associated with smithing activities. FS1.4 are small (<200mm diameter) plano-convex slag cakes which could be smithing hearth bottoms (see chapter 6.2.2) while FW3 fragments are large, straight ceramic walls which could have been part of a smithing hearth (see chapter 6.2.4). However, the relatively poor preservation of FW3 fragments prevents more certain assertion.

PM90 – SS1

PM74 – SS2

PM55 – SS3

PM113 – FW4

Figure 7.16 – Material sub-types SS1 from PM92 (top left), SS2 from PM74 (top right), SS3 from PM55 (bottom right) and FW4 from PM113 (bottom right) associated with smithing.

It is important to note that although smithing waste was recovered from only 24 sites, smithing may have taken place on many more sites. Since the assemblage was sampled from the ground surface, it consists of mixed waste material of multiple metallurgical processes. It is possible that smithing evidence at some sites was buried and therefore not identified. Another possibility is that the waste could not be differentiated from smelting waste which dominates the assemblage. Waste of both processes can sometimes be difficult to separate as they often have similar morphologies. A good example are the FS1.4 slags which could have derived from either process.

Nevertheless, it is evident from the waste discussed above, that smithing did occur on some sites. This waste, consisting mostly of small slag fragments, does not allow for an accurate identification of the process. At this stage, there is nothing to suggest different smithing methods than what was observed during the ethnographic survey (see chapter 5.1.3). That is, small ground-level hearths with a central depression and a straight charcoal retaining wall (Figure 5.12). These walls would have had a centrally placed tuyere (as seen in the ethnographic survey and fragment FW4) allowing air to be blown into the heaped charcoal. No other structures or characteristic waste were identified that could point to significant variation of this process. The presence of SS3 smithing flats suggests that primary smithing was occurring, whereby the raw iron was refined and consolidated to remove the larger proportion of slag impurities. This makes sense as the raw iron is more easily worked when still hot, straight out of the furnace, saving both time and resources. Some of the more consolidated I2 iron fragments with flattened edges (see chapter 6.2.10), recovered from 16 sites could be evidence of this refining process.

7.3 Crucible Steel Technology Groupings

Crucible steel groupings were identified from the crucible remains present on several sites in the study. The morphology of these crucible fragments are described and discussed in chapter 6.2.6. All crucibles are very similar in construction, with fine black fabrics, coarser heavily vitrified external clay layers and similar internal residues in the form of black glassy slags and metallic prills. Variation is confined to crucible shape and size, which led to the identification of three crucible types. These form the three crucible steel technological groups.

Most of the crucible steel sites have other associated material sub-types which are probably part of the crucible steel manufacturing process. One shared sub-type across all three crucible groups are GS1 green glassy fragments. These are probably heavily vitrified furnace wall but could also be vitrified lime/sandstone used in the process. Another shared sub-type is GS2 the black glassy slags. Although these were only recovered from crucible group 1 sites, they undoubtedly must have occurred on the other crucible sites but were not found during the survey. These are the remnants of the slag layer that solidified above the steel ingot within the crucibles (chapter 6.2.7). All other associated materials vary by crucible group and will be addressed separately below. A description of each crucible group will now be presented.

7.3.1 Crucible group 1

Material remains of crucible group 1 were collected from 6 sites (PM60, PM62, PM65, PM66, PM67 and PM106). In addition, crucible fragments of the same type were reported at PM63 and PM68 during the survey but not sampled. The defining characteristic of crucible group 1 is the presence of C1 crucibles (see chapter 6.2.6 for descriptions). These crucibles vary considerably in size, have flat bases and conical lids. Associated material sub-types are GS1 and GS2 glassy slags, T3 and TND4 tuyeres as well as FWND3 non-diagnostic coarse furnace wall (Table 7.12). Descriptions of all sub-types are discussed in chapter 6.

Table 7.12 - Occurrence of material sub-types by weight (g) associated with crucible group 1 by site.

		Furnace Wall		Tuyere		Crucible	Glassy Slag	
Site	**Loc.**	**FWND2**	**FWND3**	**T3**	**TND4**	**C1**	**GS1**	**GS2**
PM60	**SE-A**	3350	1975		210	15923	557	
PM62	**A**		240			3914		54
PM65	**SE-BS**	566		3521		5354	1611	151
PM66						29	23	
PM67	**SE-A**					2743	285	
PM106	**S**		534		90	7789	955	
PM63	**A**	179				?		

All furnace walls are very fragmentary and non-diagnostic. This prevents the identification of the crucible furnaces. However, the presence (at PM60, PM62 and PM106) of coarse FWND3 fragments with heavy, sometimes greyish-green vitrification, resembling that seen on some of the crucibles, suggests that the furnaces may have been made of a coarse, quartz-tempered clay (Figure 7.17). This fits with the better preserved examples identified on crucible group 2 sites (discussed below). Despite this, the poor preservation of the fragments does not permit an assessment of furnace size, shape and construction.

Other interesting associated materials are T3 and TND4 tuyeres (Figure 7.17). On the whole, T3 tuyeres appear to occur on crucible sites suggesting that they are connected to the crucible steel activities. TND4 tuyeres only occur on two sites within the assemblage (PM60 and PM106), both of which have crucible group 1 remains. It is likely that these fragments, characteristic due to the unusual external whitish-grey vitrification, were used in the crucible steel process. However, their poor preservation limits interpretation and their full size cannot be estimated.

PM60 – FWND3 external

internal

PM65 – T3 top

profile

PM60 – TND4 internal

external

Figure 7.17 – Material sub-types FWND3 from PM60 (top), T3 from PM65 (centre) and TND4 from PM60 (bottom) associated with crucible group 1.

7.3.2 Crucible group 2

Crucible steel technological group 2 remains were collected from 8 sites (PM18, PM19, PM54, PM58, PM88, PM119, PM128 and PM133). In addition, crucible fragments were reported at PM55 during the survey but not sampled, while non-diagnostic fragments were recovered from another five sites (PM9, PM84, PM87, PM89 and PM91). Their proximity to other crucible group 2 sites and the presence of similar, small crucible remnants suggest that they were part of this technological group. The defining characteristic of crucible technology group 2 is the presence of C2 crucibles (see chapter 6.2.6 for descriptions). These crucibles are relatively small and uniform in size, have rounded bases and small domed lids. Associated material sub-types are GS1 glassy slags, T3 tuyeres as well as FW2 and FWND3 coarse furnace walls. The presence of many FW3 straight furnace walls on many of these sites suggests that they may also be associated (Table 7.13). Descriptions of all sub-types are discussed in chapter 6.

Table 7.13 – Occurrence of material sub-types by weight (g) associated with crucible group 2 by site.

		Furnace Wall			**Tuyere**	**Crucible**		**Gla.Slag**	**Geo.**
Site	**Loc.**	**FW2**	**FW3**	**FWND3**	**T3**	**C2**	**CND**	**GS1**	**G6**
PM18	**SE-A**	2542	2370	1760		2270	60	5	10370
PM19	**SE-A**					546			
PM54	**A**			522	531	550		37	
PM58	**A**	5776		30		2132		856	
PM88	**A**		480	1150	274	2713		167	
PM119	**SE-BS**	1502	2390			497		251	
PM128	**A**					1545		2221	
PM133	**SE-BS**					80			
PM9	**S**						448		
PM55	**A**		2040	4430	650	?		1350	
PM84	**SE-A**			1782			158		
PM87	**A**		3580				156		
PM89			73				10		
PM91	**A**		438				210		

The presence of better preserved FW2 furnace wall fragments is interesting. These only occur on crucible group 2 sites PM18, PM58 and PM119, suggesting that they are directly associated with crucible steel production. They are made of very coarse quartz-tempered clay and are coil built (Figure 7.18). The curvature on the better preserved example from PM58 indicates an internal diameter in excess of 500mm. The presence of non-diagnostic, coarse FWND3 furnace wall fragments on several other sites also suggests that similar furnaces might have been in operation. Of particular interest is the geological, G6, fragment found at PM18 (see chapter 6.2.9). This stone fragment is a furnace base (Figure 7.18). The internal surface is partially covered with vitrification, seemingly of a coarse clay. The absence of slag and the fact that the coarse wall fragments appear to match the curvature of the stone, indicates that this was a base of a crucible furnace (Figure 7.18). Due to the poor preservation of the majority of the furnace wall fragments, the internal diameter is difficult to estimate but is likely to be around 400-500mm. Three sites (PM54, PM55 and PM88) have type T3 tuyeres. These are very fragmentary but are clearly larger and thicker-walled than other tuyere types (Figure 7.18). Since most T3 tuyeres occur on crucible sites, it is likely that they are associated with the steel making operation. Therefore, crucible technology group 2 furnaces were made of a coarse fabric, coil built and around 400-500+mm in internal diameter, with a stone base (at least at PM18) and T3 tuyeres.

Another interesting observation is that seven crucible group 2 sites have FW3 wall fragments. These are straight with no curvature and were interpreted as smithing hearth charcoal-retaining walls (see chapter 6.2.4). In this case it would suggest that smithing also took place on crucible steel sites. However, it is also possible that they could be walls built to protect the bellowers from the high temperatures emitted from the furnaces. Such structures have been described by Coomaraswamy in his account of crucible steel production at Mawalgaha (Coomaraswamy 1956, 192-3). Their poor preservation negates further interpretation.

PM58 – FW2 exterior interior

PM18 – G6 PM55 – T3

Figure 7.18 – Material sub-types FW2 from PM58 (top), G6 from PM18 (bottom left) and T3 from PM55 (bottom right) associated with crucible group 2. Note the superimposed coarse wall fragment matching the curvature of the stone G6 crucible furnace base from PM18 (refer to chapter 6.2.9 for additional photos and discussion).

7.3.3 Crucible group 3

The remains of crucible steel technological group 3 were collected from 5 sites (PM74, PM75, PM101, PM102 and PM103). The defining characteristic of crucible group 3 is the presence of C3 crucibles (see chapter 6.2.6 for descriptions). These crucibles vary considerably in size, have flat bases and domed lids. Associated material sub-types are GS1 glassy slags, T3 tuyeres as well as geological G3 fragments (Table 7.14). Descriptions of all sub-types are discussed in chapter 6.

Table 7.14 – Occurrence of material sub-types by weight (g) associated with crucible group 3 by site.

		Furnace Wall			Tuyere	Crucible		Gla.Slag	Geo.
Site	**Loc.**	**FWND1**	**FWND2**	**FWND3**	**T3**	**C3**	**CND**	**GS1**	**G3**
PM74	**SE-A**		6096			952			
PM75	**A**		725		1334	4757			1400
PM101	**SE-A**	142				146			
PM102	**S**	1737			302	3110	180	250	975
PM103	**S**			1580		2220			865

The furnace wall material on all these sites is fragmentary and for the most part non-diagnostic. The examples from PM74 and PM75 appear to be furnace lining characteristic of the smelting group 8. There is no evidence of crucible furnaces unless these were made of a similar fabric to the smelting furnaces. On the other sites (PM101, PM102 and PM103), there is evidence of coarse, quartz-tempered furnace walls more in line with those of crucible groups 1 and 2. These are present in the form of fully or partially vitrified non-diagnostic FWND1 and FWND3 fragments (Figure 7.19). Due to the poor preservation of these examples, the size, shape and method of construction of the crucible furnaces cannot be estimated. The presence of T3 tuyeres at PM75 and PM102 suggests that they were related to the crucible steel activities on site. These differ slightly in fabric. The fragments from PM75 are fine, dominated by a fibrous and cereal organic component, while the examples from PM102 are low-coarse and silty with minor quartz and organic inclusions (Figure 7.19). These differences in furnace and tuyere fabrics are significant and probably represent a process variation at these sites.

Another interesting feature is the presence of G3 geological fragments (see chapter 6.2.9 for descriptions) at PM75, PM102 and PM103 (Figure 7.19). These only occur on crucible group 3 sites and must represent a variation in the process from the other two crucible technological groups. Without the scientific analysis of these fragments it is not possible to identify what they are made of. However, their molten nature and numerous charcoal voids and impressions suggests that they formed within the crucible furnace. They are most probably vitrified furnace lining or a geological component placed in the furnace to either protect, divide or provide support for the crucibles. In any case, this material was part of the furnace structure or process.

PM102 – FWND1

PM103 – FWND3

PM75 – T3

PM102 – T3

PM74 – G3

PM102 – G3

Figure 7.19 – Material sub-types FWND1 from PM102 (top left), FWND3 from PM103 (top right), T3 from PM75 and PM102 (centre) and G3 from PM74 and PM102 (bottom) associated with crucible group 3.

7.3.4 Summary

Three crucible technological groups were identified, each coinciding with the crucible sub-types discussed in chapter 6.2.6. The poor preservation of the furnace walls and tuyeres prevents the accurate identification of furnace size and shape, particularly for crucible technology groups 1 and 3. Nevertheless, the better preserved technical ceramic examples of crucible group 2 suggest that the furnaces were made of a very coarse quartz-tempered coil built fabric. The inner diameter of the furnaces was likely to be around 400-500+mm and they probably had a stone base. The presence of similar coarse fabrics from sites of crucible groups 1 and 3 sites suggests that similar furnaces may have been employed. The large T3 tuyeres appear to preferentially occur on crucible sites and are associated with these technologies. Their fabrics vary slightly from medium to coarse quartz-tempered at crucible groups 1 and 2 sites and fine to low coarse organic-tempered at crucible group 3 sites. Some crucible group 1 sites also have TND4 tuyeres which could be associated with the steel manufacturing process. The presence of these varying material forms undoubtedly represents process variation between and within crucible technological groups but these cannot be fully assessed due to the generally poor preservation of the waste material. All crucible groups had GS1 and most likely GS2 glassy slag fragments but only crucible group 3 sites contained G3 geological material. The similarity in waste material (crucible manufacture and associated materials) indicates that the overall processes were similar but that there was some variation in furnace construction and operation. The morphology of the crucibles and associated remains does not permit the identification of the operating process, either by carburisation or co-fusion as discussed in chapter 2.

7.4 Analysis of Data and Discussion

Having outlined the main smelting and crucible steel technology groupings in the study area, it is now important to look at their spatial distribution, assess trends in location setting and evaluate their inter-relationships.

7.4.1 Spatial Distribution of Smelting Technology Groups

Sites were plotted onto a map by smelting technology group, revealing two main site concentrations with different technological operations (Figure 7.20). The first and largest group (A) forms the core research area, some 60km wide west-east and 50km north-south (Figure 7.20). The majority of sites fall within the north-western part of Karimnagar district with some encroaching upon southern Adilabad and western Nizamabad district. This group encompasses the majority of sites surveyed and is dominated by smelting groups 1, 1.1 and 2. The second group (B) is situated c.30km south-east of Jagtial. It is much smaller, consisting of only eight smelting sites within a radius of c.3.5km (Figure 7.20). These sites comprise all the evidence for smelting groups 3, 4, 6 and 7. In addition to these two main groups are a small number of outliers. PM74 and PM75 (Parasurampalli village) in Warangal district are situated c.100km south-east of the main group A and are the only examples of smelting group 9 (Figure 7.20). The other outliers are PM101, PM102 and PM103 (Gopalpur village) situated c.60km south of group A but the smelting assemblage collected there is too sparse to identify the specific smelting grouping. The other site is PM104 (Dacharam village) c.5km north-east of these sites which has evidence for smelting group 5 (Figure 7.20).

B. Girbal

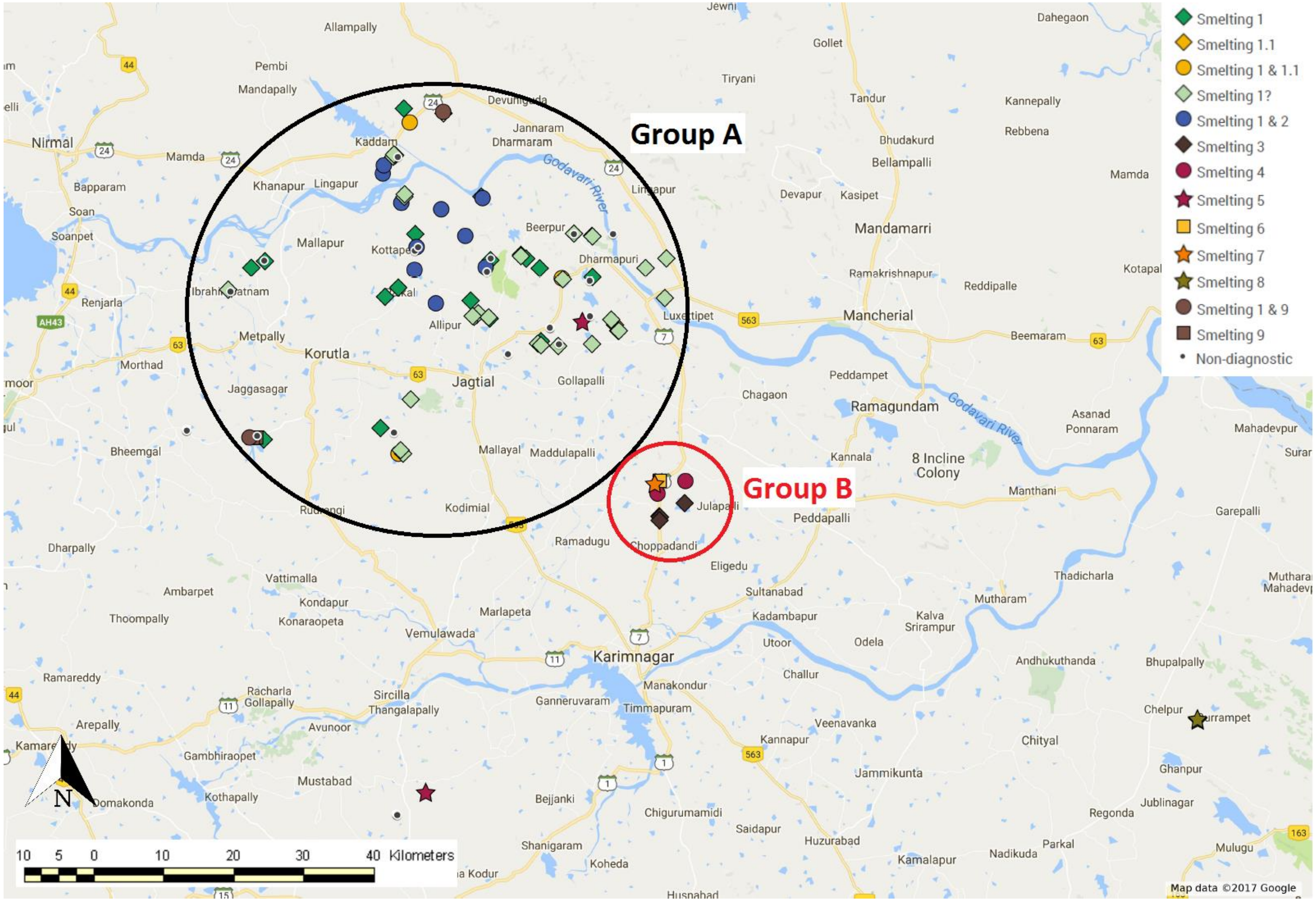


Figure 7.20 – Distribution of smelting technology groups. Note the two main site concentrations – group A and group B.

In the core research area, group A sites prevail, dominated by smelting technology group 1. However, there is further spatial variation within A. Most smelting group 2 sites are located in and around the forested area north of Jagtial, whereas smelting groups 1 and 1.1 have a much more widespread distribution across the region. It is interesting that all sites with smelting group 2 evidence also have smelting group 1 remains. The possible explanations for this are, that they are either both contemporary but produced different end products, or that they are temporally distant and represent an evolution or progression of technology in this area. This is difficult to determine without dating evidence but the relatively well-preserved smelting group 1 remains at some sites suggests that some of these metallurgical activities were relatively recent. Its overwhelming presence in the region indicates that smelting group 1 was a standardised smelting technology used at the height of metallurgical production, with smelting groups 1.1, 2, 5 and 9 being earlier in date, or localised variations due to the idiosyncratic practices of individuals or groups. It is important to mention that the varying furnace fabrics found on smelting group 1 sites (chapter 7.1.1) could also represent temporal or idiosyncratic variation of smelting activities on these sites.

It is clear from the spatial distribution groupings that dominant smelting technologies differ geographically. None more so than group A and group B, suggesting that smelting traditions were different in those areas. This variation could be attributable to several reasons. Smelting may have been controlled by different groups of people with their own traditions. Perhaps group A and B fell under different regional control. Another possibility is that different products were manufactured, with each area specialising in a particular technology. Different types of iron production or process variations could have been employed depending on the end usage of the product, such as crucible steel, agricultural tools or weapons. It is also possible that the difference in technology is temporal, with certain technological preferences employed in different time periods. Unfortunately, the lack of stratigraphic and dating context for any of these surface finds limits interpretation, particularly for temporal clarification.

The numerous different smelting technology groupings identified, prove that this region had a rich and diverse metallurgical tradition and variation could be attributable to all three reasons outlined above. Nevertheless, the striking differences between group A and group B sites points to production by different groups of people. In such a large survey area, spatial variation is expected and the outliers further south also reinforce the notion that there must have been local or regional smelting variation. However, without the scientific analysis of the waste material it is not possible to verify if these technologies produced different end products. The morphology of the waste suggests that all were iron smelting operations, most probably producing low-carbon raw iron as in the western 'bloomery' tradition.

The body of data synthesised here holds significant potential for contributing to a much wider theoretical debate on the nature of 'technological choices', as exemplified by Jones (2002), Killick (2004), Lemonnier (1993), and Sillar and Tite (2000). Such a debate is beyond the scope of this current study but will be the focus of future analysis.

7.4.1.1 Smelting in Relation to Location Setting

The assessment of the location setting of each smelting technology group may reveal more on their origins and function. The location settings defined were explained in chapter 4.1.2. Figure 7.21 shows the number and proportion of site settings for each smelting group. The dominant smelting technology group 1 (including groups 1.1 and 1?) are found in varied settings. Approximately half of these sites are found on settlements (S) and their edges (SE) while the other half are located in more rural environs; mostly agricultural land (A) but also bare scrubland (BS) and forests (F) (Figure 7.21). This is further evidence for a well-established technology which was in use in all landscape settings. Of particular interest are smelting technology group 2 sites, which fall within the main site grouping A. Unlike group 1, these preferentially occur outside village settings, within agricultural land (A) and forests (F). Therefore, it seems possible that a different group of people were responsible. However, it is also worth considering (as mentioned in chapter 7.1.2) that the diagnostic waste materials for smelting group 2 are much more fragile and prone to breaking up post-deposition. Hence, it is possible that evidence for this technology on settlement sites, which tend to be the most disturbed, has degraded beyond recognition.

The location settings of smelting technologies in group B are also interesting. All smelting group 3 sites are located within or on the edge of settlements (S and SE), while all smelting group 4, 6 and 7 sites are on agricultural land (A). Therefore, it is possible that different groups of people were involved in their operation. They may also be temporally distant but once again the lack of dating context limits interpretation. Their end products could have been different. This is especially true for the smelting group 7 site (PM35) where the waste differs most from any other identified smelting technology group (see chapter 7.1.7). If these are contemporary, it is possible that settlements had more centralised smelting operations while different groups of people with different technological traditions were allowed to operate outside village boundaries. Perhaps, smelting group 7 was a refining site of the end products of the other surrounding smelting technology groups. Without stratigraphic or dating context it is hard to interpret their function and inter-connection any further. Nevertheless, the trends identified are valuable and could be enlightened by further work.

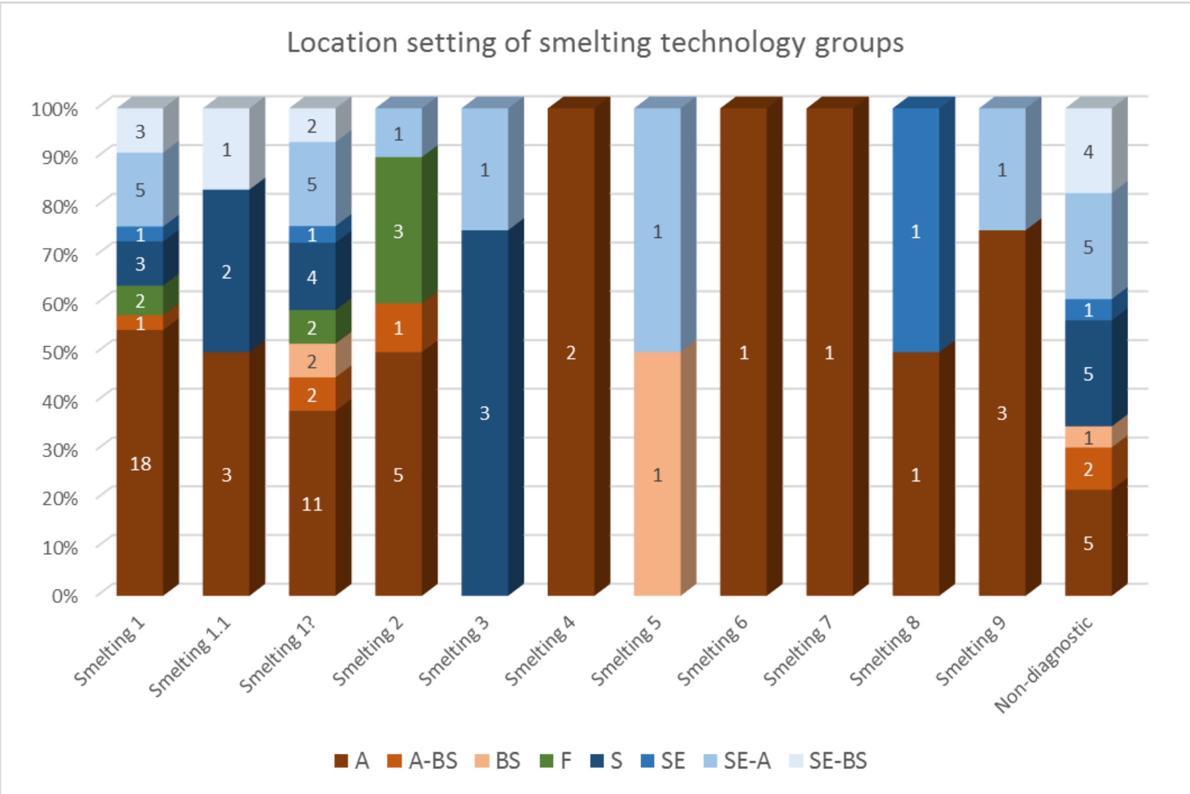


Figure 7.21 – Number and proportion of site settings by smelting technology groups.

It is important here to discuss the observations made by Lowe (1995) which have been summarised in chapter 2.3.1. She suggests that smelting technology may have varied depending on the surrounding geology and use of different ores, most notably lateritic ores and magnetite. However, her fieldwork targeted a geographical area which has a more varied geology further to the south-west of this study. All sites surveyed in this study are located on the same geology; tonalite-granodiorite (pink and grey granite) from the Peninsular Gneissic Complex with large outcrops of banded magnetite-quartzite from the Charnockite Group (Geological Survey of India 2016). The only exceptions are the sites in and around Konasamudram (PM65 and PM67) and Konapur (PM60, PM61, PM62, PM63 and PM64) which are the most westerly sites surveyed. These are located close to or on basalt of the Deccan Trap.

Unfortunately, the smelting assemblage collected from the majority of these westerly sites are quite sparse and incomplete, with very little diagnostic technical ceramics and slags. This prevents the more precise identification of the smelting technology. Nevertheless, PM60, PM62 and PM63 have noticeably different tuyere types and were characterised as smelting technology group 9. Therefore, it is possible that a different technology was in operation there, relating to the type of ore smelted but the general lack of diagnostic waste material prevents assertion. In addition, no ores were found on any of these westerly sites. Both PM63 and PM64 also have evidence for the more common smelting technology group 1 which raises further doubts as to whether or not there was a significant difference in technology. The majority of the ore collected from the sites surveyed are banded magnetite and there is no evidence to point to another source of iron ore. Further work would be required to verify Lowe's observations. The expansion of the survey west, into the Deccan Trap, would be particularly useful. It is now important to assess the spatial distribution and location settings of the crucible technology types.

7.4.2 Spatial Distribution of Crucible Technology Groups

The crucible sites were plotted onto a map by crucible technology group, revealing a clear geographical separation of the three main groups (Figure 7.22). Crucible group 1 sites are all situated in the western-most part of the survey area, close to the boundary between Nizamabad and Karimnagar district (Figure 7.22). They comprise seven sites in three groupings around the villages of Konasamudram (PM65, PM67 and PM68), Konapur (PM60, PM62 and PM63) and Ibrahimpatnam (PM106). Crucible group 2 sites are more numerous and scattered over a larger area, east of crucible group 1 sites. The majority are in the north-western part of Karimanagar district, but two (PM55 and PM58) are situated further north in Adilabad district (Figure 7.22). Crucible group 3 consists of four sites concentrated in the two most southerly surveyed villages; Gopalpur (PM101, PM102 and PM103) in Karimnagar district, and Parasurampalli (PM75) in Warangal district (Figure 7.22).

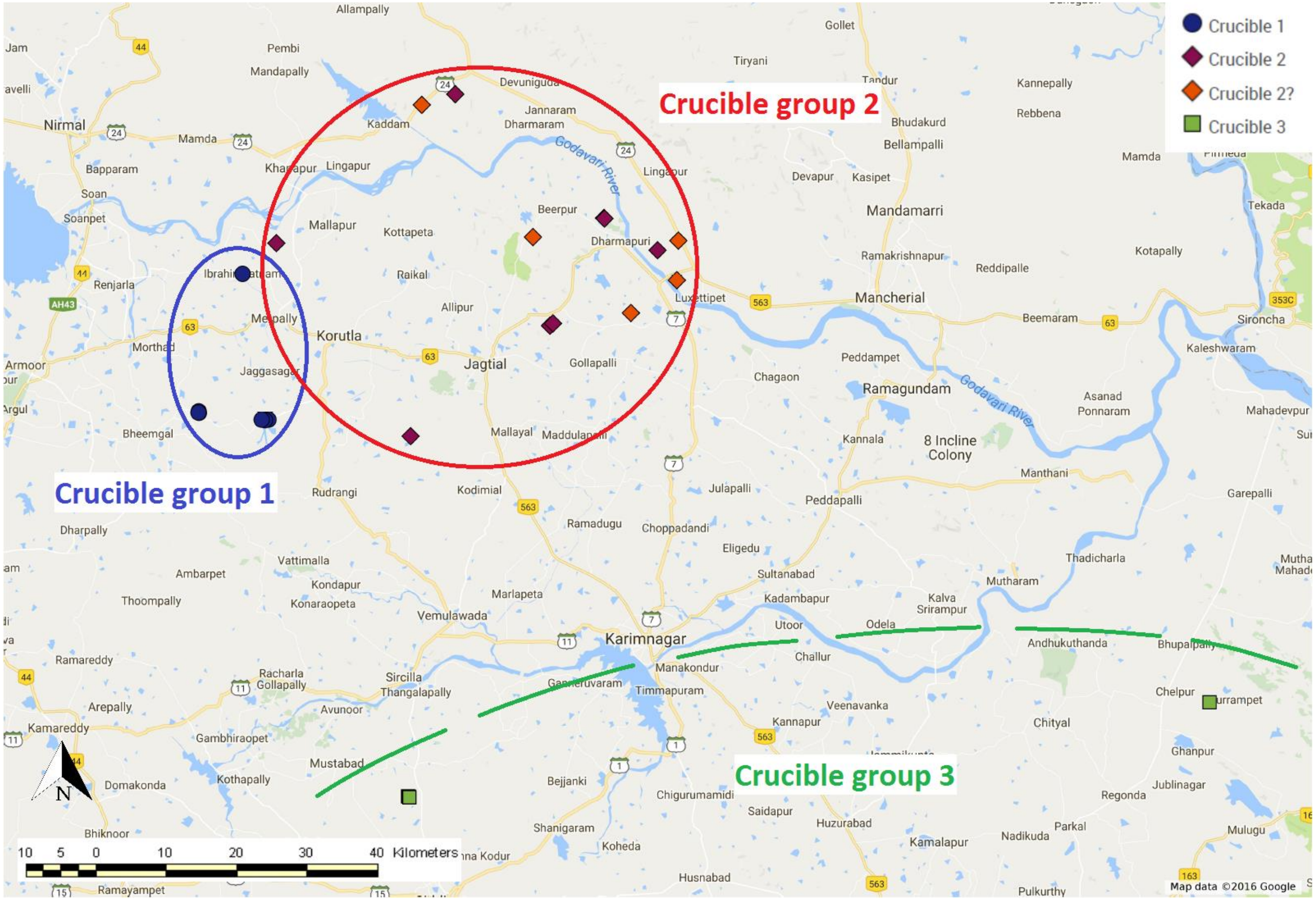


Figure 7.22 – Distribution of crucible technology groups. Note the geographical concentration of the three main crucible groups.

The spatial distribution of the different crucible technology groups suggests that there was localised variation in crucible steel production. Due to the generally poorly preserved remains found on crucible sites, the nature and scale of this variation is uncertain. The collected materials reveal little of the original furnace structures and operating processes (see chapter 7.3). There is little to suggest at this stage that the manufacture and operation of crucible steel was different, beyond variation in crucible size and form. However, crucible morphology is significant and the presence of different material types on some sites suggests that there was some operational variation. Before potential reasons for this variation are assessed, it is important to compare site specialisation and the location settings of each of the crucible technology groups.

7.4.2.1 Site Specialisation and Location Setting of Crucible Steel Technology Groups

In order to assess site specialisation, the proportion and number of site types (as set out in chapter 4.1.2) in relation to crucible technology groups is presented in figure 7.23. It is evident that there is a difference in site specialisation within the three crucible technology groups. Crucible group 1 sites are almost all crucible/smelting sites, suggesting that crucible steel was the main focus and output. The only exception is PM63, which is located outside Konapur village. Although crucibles were observed during the survey, none were collected and they appeared to be secondary to the smelting activities. Nevertheless, it is likely that the operations were associated with the more crucible-specialised adjacent sites in and around the village (PM60 and PM62 – see chapter 5.1.4). Crucible group 2 sites, on the other hand, are almost all smelting/crucible sites, suggesting that iron smelting was dominant with crucible steel production being a secondary activity. PM119 is the only exception, where more crucible waste was identified. Crucible group 3 sites are split between those with more crucible steel production waste and those with more iron smelting waste. However, the two smelting/crucible sites (PM101 and PM102) lie within the same village as PM103 (chapter 5.1.4), where more intensive crucible steel production appears to have taken place. Therefore, it is possible that the waste found on PM101 and PM102 is secondary, originally deriving from PM103.

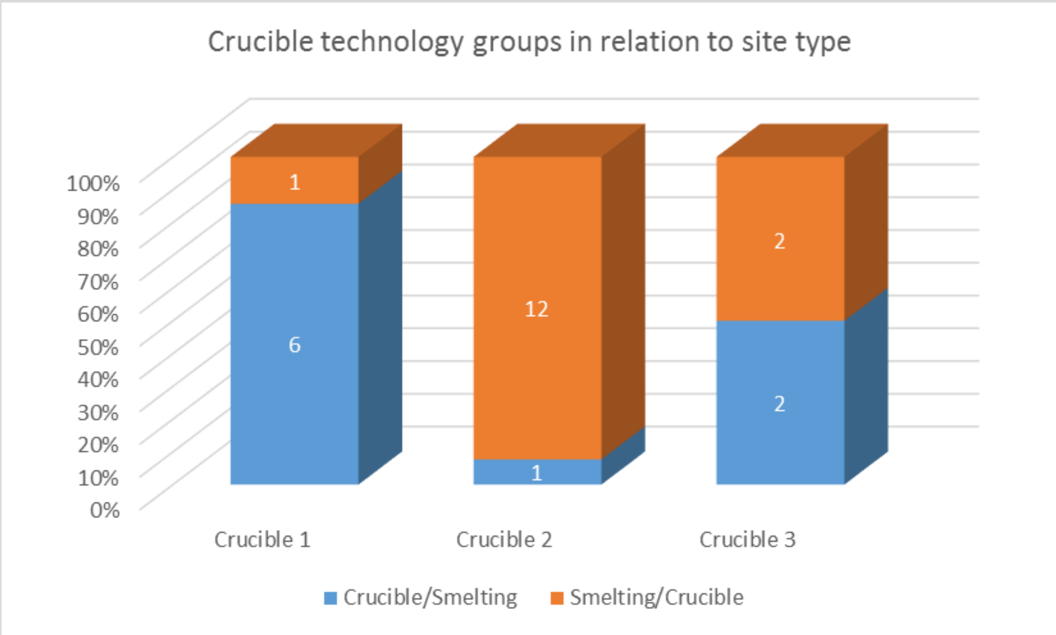


Figure 7.23 – Number and proportion of site types by crucible technology group.

Differences are also noticeable when comparing location setting to crucible technology groups (Figure 7.24). Both crucible group 1 and crucible group 3 sites have a greater tendency to be within or on the edge of settlements (S and SE). The three examples that are not, are still relatively close to a village. PM62 and PM63 (crucible group 1) are both within 850m of Konapur village, while PM75 (crucible group 3) is within 300m of Parasurampalli village. Crucible group 2 sites, on the other hand, are located in more varied settings. The majority fall outside settlements, within surrounding agricultural land (A) or on settlement edges (SE). On the whole, crucible groups 1 and 3 sites are also larger with a greater amount of crucible steel production waste observed in the field.

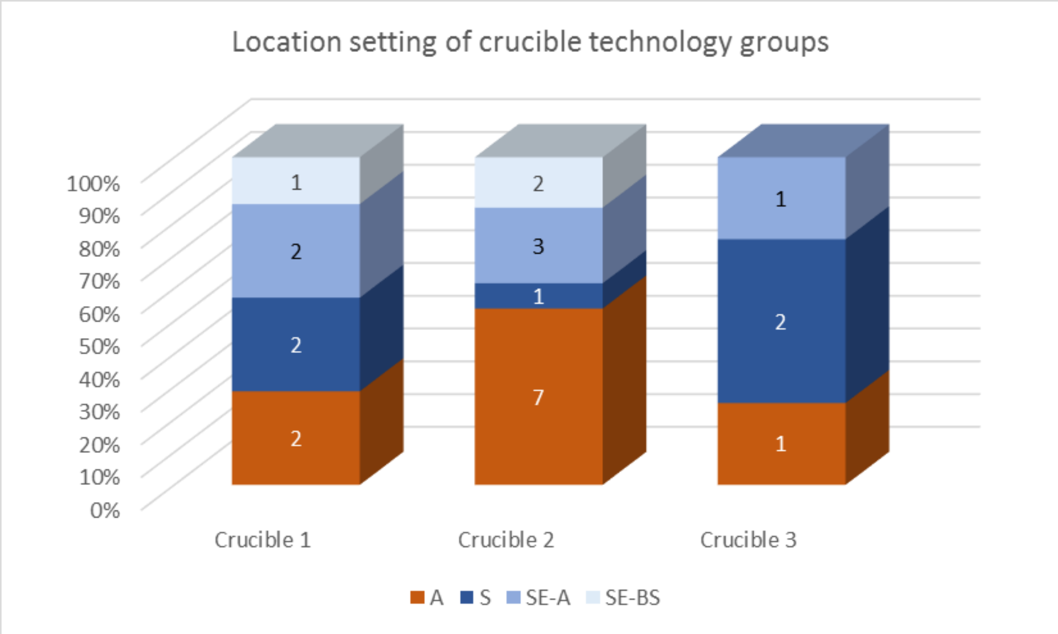


Figure 7.24 – Number and proportion of site settings by crucible technology group.

Therefore, it is possible to say that crucible group 1 and 3 sites are, for the most part, larger and more specialised crucible steel production sites. They also appear to be more centralised within or close to settlements. In contrast, crucible group 2 sites tend to be smaller with less crucible steel production waste, and dominant smelting remains. They are scattered over a larger area and are most often found in agricultural land or on settlement edges.

As with the smelting technologies, this variation could be attributable to several reasons. The operations may have been under the control of different groups of people with their own crucible steel manufacturing traditions. It is possible that the end product was also different, intended for a different usage or made for a different consumer. Perhaps the smaller-scaled but more numerous crucible group 2 sites were intended for local supply, while the larger crucible group 1 and 3 sites were intended for external and long-distance trade. If so, it may account for the smaller size of the type 2 (C2) crucibles which would have produced smaller ingots, more favourable for smaller everyday cutting tools. This would be in contrast to perhaps a larger demand for trade, more likely targeted at weaponry (swords), as implied by Voysey's (1832) account and Tavernier (1679), requiring larger ingots.

It is also possible that the crucible group 2 sites produced a feedstock for the other crucible types. Since no archaeological evidence to date has been found for the production of cast iron, required for the production of crucible steel by co-fusion, perhaps the higher carbon steel ingots produced in type 2 crucibles was feedstock for a two (or multiple) part process. In saying that, it is important to state that at this stage there is no apparent difference in the waste material examined except that of crucible size and shape (see chapters 6.2.6 and 7.3). Therefore, it seems unlikely that the end product was significantly different, but further scientific analyses of the crucibles and waste in the following chapter may reveal more.

The variation in crucible form could also be temporal, indicative of an evolution or development of crucible steel production. Crucible group 2 sites could represent earlier evidence of small scale localised production, which was perhaps then intensified and centralised on crucible group 1 or 3 sites as the demand for the product increased and external trade developed. The fact that all crucible group 1 and 3 sites are large, more specialised in crucible steel than smelting, and centred within or close to settlements would add credence to this argument. Conversely, the smaller crucible group 2 sites could be later, representing a decentralisation of production into more numerous but smaller and less specialised production centres. However, once again due to the lack of dating evidence it is not possible to clarify a timescale for production. Nevertheless, the nature of the evidence, the variation in crucible size and shape as well as the difference in manufacturing scale and specialisation, suggests that the operations were controlled by different groups of people, perhaps during different time periods.

7.4.3 The Inter-relationship between Smelting and Crucible Steel

It is now important to assess the interrelationships of crucible and smelting technologies. As discussed in chapter 5, all crucible steel sites also had evidence of smelting. The material of both technologies is often mixed suggesting that the activities were contemporary and likely to be in operation at the same time. All crucible sites fall within the main smelting group A (crucible groups 1 and 2) or are part of outlying sites on the southern boundaries of the surveyed area (crucible group 3) (Figure 7.25). It may be significant that no crucible remains were found in smelting group B suggesting that the technologies present there had no association with crucible steel production.

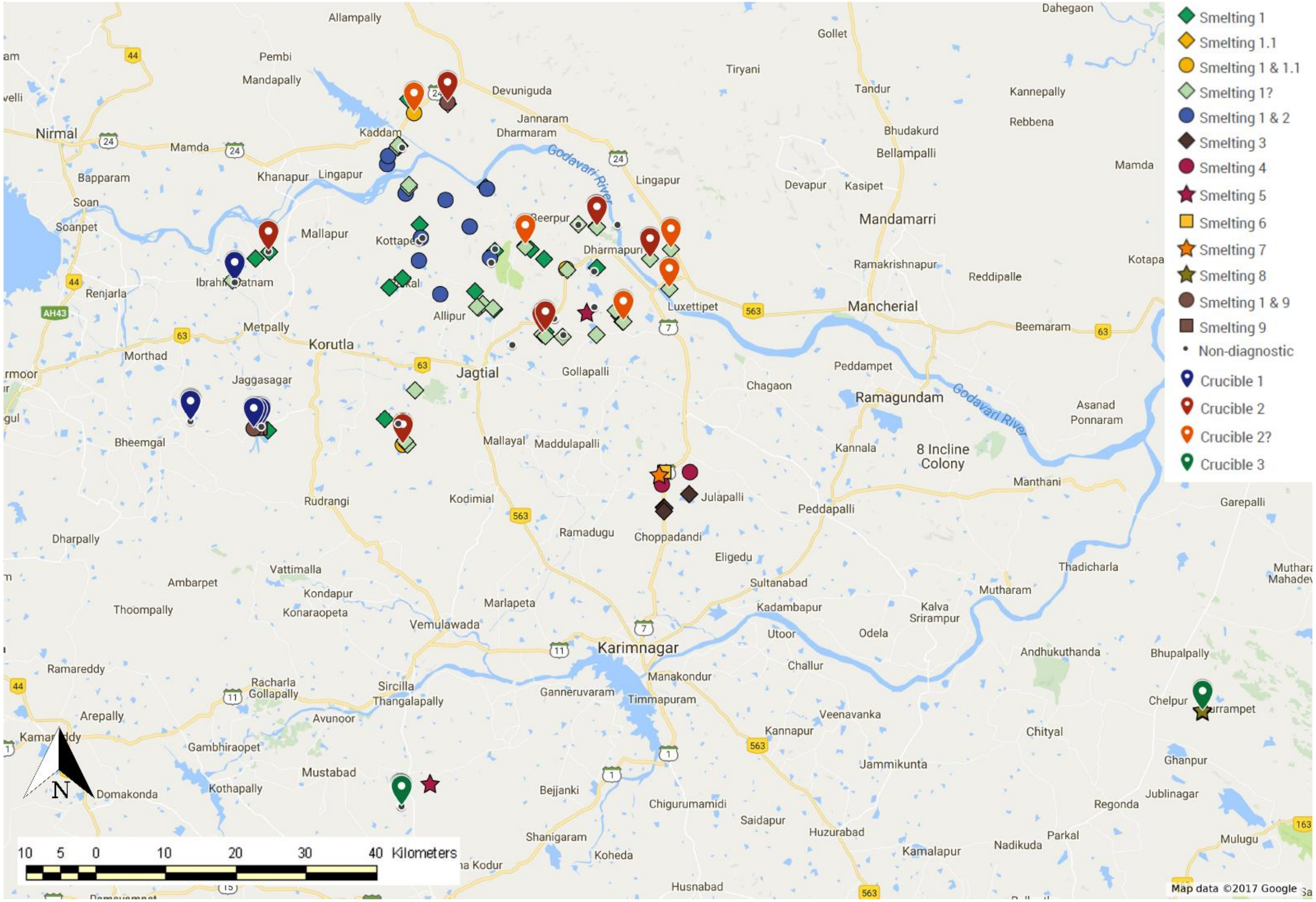


Figure 7.25 – Distribution of smelting and crucible steel technology groups. Note most crucible sites within main research area with a few outliers on the southerly sites.

The smelting technology groups present on crucible steel sites have been plotted in figure 7.26. The majority of smelting technologies on crucible group 1 and 3 sites are non-diagnostic. As mentioned above, most of the remains were associated specifically with crucible steel, smelting forming a minor component. Therefore, less smelting waste was collected, with fewer diagnostic technical ceramics and slags, preventing better identification or classification of the smelting activities. Nevertheless, the material was more diagnostic on a few sites. Two crucible group 1 sites (PM60 and PM62) had evidence for smelting technology group 9 and another (PM63) had both smelting groups 1 and 9. PM75 is the only crucible group 3 site with diagnostic smelting remains for smelting group 8. In contrast, most metallurgical activities on crucible group 2 sites were diagnostic, the only exception being PM133 where very little material was collected. The dominant smelting technologies were smelting groups 1 and 1.1. However, the collected remains on six sites were not complete enough to identify which of these (smelting 1 or 1.1) was in operation and were hence labelled as smelting 1?. Only one site (PM58) had evidence of smelting technology group 9 but the material was mixed with that of smelting group 1.

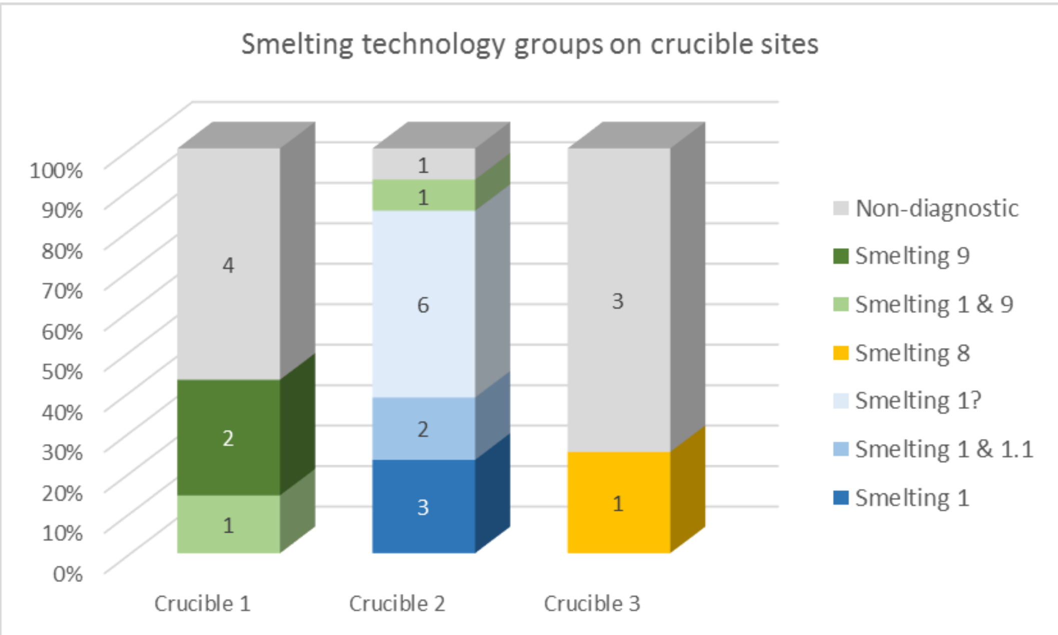


Figure 7.26 - Number and proportion of smelting technological groups on crucible sites.

The fact that the majority of crucible group 1 and 3 sites have non-diagnostic smelting remains, limits discussion to some extent. Nevertheless, at first glance it appears as if each crucible technology group had different associated smelting operations – smelting group 9 on crucible group 1 sites, smelting groups 1 and 1.1 on crucible group 2 sites and smelting group 8 on crucible group 3 sites. However, it is important to consider that smelting group 9 is for the most part non-diagnostic. Smelting group 9 was characterised as distinct due to the presence of T1 tuyeres but little of the other waste material collected was diagnostic. The presence of these tuyeres suggests that something different was occurring but this variation cannot be fully assessed. In addition, PM63 also has evidence for the more common smelting technology group 1 which is dominant on crucible group 2 sites, and crucible group 2 site PM58 has evidence of smelting group 9. This suggests that smelting variation was not closely correlated to the type of crucible technology operating on the site. Since all smelting group 9 sites are on the periphery of the main research area, they are likely to represent localised smelting variations. It is possible that if the survey was extended further west, more sites with this technological variant would be identified. A similar situation is present on PM75, the only diagnostic smelting remains on a crucible group 3 site. The smelting here was classified as smelting group 8 but the technology is very similar to smelting group 1, the major difference being in furnace and tuyere fabric composition and the presence of unusual tuyere fragments.

As a whole, there is no evidence to suggest specialised smelting or other metallurgical activities operating on crucible sites of any group. Indeed, the pattern of smelting activities appear to be identical to the dominant smelting technology in their respective geographical area. This suggests that crucible steel was very much embedded within the larger metallurgical tradition of Northern Telangana. Interpretation and clarification of a temporal sequence is limited by the lack of dating but the large scale nature of some of these sites and the evident variation in crucible form indicates a long tradition of crucible steel production.

7.5 Conclusion

The assessment of the collected materials and their preferential occurrence on sites, enabled the identification of nine iron smelting and three crucible steel technological groups. Tables 7.15 and 7.16 provide a summary of the major features, associated materials as well as the sites and most common location settings of each crucible and smelting group. With the exception of smelting group 7, all iron smelting is consistent with the solid state reduction of iron ores, most probably banded magnetite. Despite the variation, the dominance of one technology throughout the region (smelting group 1) indicates that at some point there was a standardisation of iron smelting technology. The three crucible technologies appear to be very similar. There is no evidence pointing to any major difference in crucible construction or operating process, except that of crucible size and shape. Their morphology alone is not enough to determine if the process was by carburisation or co-fusion, as discussed in chapter 2. However, the scientific analysis of the crucible fabrics and related waste in the following chapter may shed more light in this regard.

Table 7.15 - Summary of crucible technology groups outlining associated materials and major features as well as the sites and most common location settings on which they are found. Materials in bold are either dominant or define the technological groups while location settings in bold are where they are most commonly found.

Cruc. Group	**Materials**	**Features**	**Sites (PM)**	**Loc. Setting**
1	FWND2, FWND3, T3, TND4, **C1**, GS1, GS2	Crucibles: large size range, conical lids, flat bases, tongue marks; coarse furnace walls	60; 62; 65; 66; 67; 106 Likely: 63	A, **S**, **SE**
2	**FW2**, FW3, FWND3, T3, **C2**, GS1, **G6**	Crucibles: small uniform size, domed lids, curved bases; coarse coil built furnaces; 400-500+mm internal furnace diameter; possible stone furnace base	18; 19; 54; 58; 88; 119; 128; 133 Likely: 9; 55; 84; 87; 89; 91	**A**, S, SE
3	FWND1, FWND2, FWND3, T3, **C3**, GS1, **G3**	Crucibles: large size range, domed lids, flat bases; coarse furnace walls; unidentified geological G3 fragments	74; 75; 101; 102; 103	A, **S**, **SE**

Table 7.16 - Summary of smelting technology groups outlining associated materials and major features as well as the sites and most common location settings on which they are found. Materials in bold are either dominant or define the technological groups while location settings in bold are where they are most commonly found.

Smelt. Group	Materials	Features	Sites (PM)	Loc. Setting
1	**FW1**, FWND3, **T2**, **FS1**, **FS1.1**, FS2, FS2.1, TS1, TS1.1, TS2	Slag tapping; c.250-350mm furnace internal diameter; slab built around branches or reeds; charcoal fines at base of furnace; tuyeres placed in wall at 30-40˚ downward angle	18; 22; 40; 44; 45; 46; 47; 49; 52; 54; 55; 56; 58; 63; 64; 69; 77; 82; 84; 85; 93; 95; 99; 100; 112; 113; 116; 118; 125; 128; 131; 132; 134	**S**, SE, **SE-A**, **SE-BS**, **A**, A-BS, **F**
1.1	FW1, FWND3, T2, **FS1.2**, FS2, FS2.1, TS1, TS1.1	Slag tapping; c.200-250mm furnace internal diameter; furnace base not lined with charcoal fines	8; 22; 46; 55; 73; 128	**S**, SE-BS, **A**
1?	Same attributes as smelting groups 1 and 1.1 above but assemblages less complete		9; 14; 19; 21; 38; 39; 42; 51; 57; 72; 76; 79; 80; 83; 87; 88; 91; 92; 94; 97; 108; 110; 111; 119; 120; 124; 127; 129; 130	**S**, SE, **SE-A**, **SE-BS**, **A**, A-BS, **BS**, **F**
2	FWND2, **FWND3**, T2, T3, **FS1**, **FS5**, TS1, TS1.1	Slag tapping; c.600mm furnace internal diameter; coarse furnace fabric; purposely dug pit at front of furnace for tapped slag; surrounding stone features	46; 79; 80; 112 Possible: 49; 76; 99; 100; 118; 116	SE-A, **A**, A-BS, **F**
3	FWND1, FWND3, **FS1.2**, FS2, FS3, FS5.1, TS1, TS1.1, **TS2**, **G1**	Slag tapping; c.200-250mm furnace internal diameter; coarse clay fabric; large stones in furnace wall	24; 26; 27; 34	**S**, SE-A
4	FWND2, **T1**, **FS1.3**, FS5, FS5.1, TS1.2	Slag tapping; coarse clay fabric; base of furnace lined with clay?; poor preservation of remains	28; 31	**A**
5	**FWND2**, **T1**, **FS2.1**, FS5, FS5.1, TS1, TS3	Slag tapping (channelled away from furnace); dominance of FS2.1 slags; poor preservation of remains	3; 104	**SE-A**, **BS**
6	FW1, FS5, **FS6**, TS1, TS1.1, TS3	Slag tapping; very porous slags; poor preservation of remains	30	**A**
7	FW1, **TND3**, **FS1.5**, FS5.2, TS1, TS3, G1	Slag tapping?; <150mm internal furnace diameter; a refining process?	35	**A**
8	**FW1**, FWND2, **T2**, **T4**, **FS1.1**, **FS1.2**, FS3, FS4, FS5, FS5.1, TS1, TS1.2, TS2, TS3	Slag tapping; c.280-360mm internal furnace diameter; fine silty quartz, organic and slag tempered fabrics; gritty textured porous slags; charcoal fines at base of furnace	74; 75	**SE**, **A**
9	FWND2, FWND3, **T1**, FS1.2, FS2.1, FS5, TS1, **TS2**	Slag tapping; poor preservation of remains	58; 60; 62; 63	SE-A, **A**
Non-Dia.	10; 11; 48; 50; 65; 67; 70; 90; 96; 98; 101; 102; 103; 106; 115; 117; 123; 133; 135; 137			N/A

Both smelting and crucible steel technological groups were mapped to assess spatial distribution. Two main smelting site groupings (A and B) were identified with different dominant technologies suggesting regional variation of smelting processes. A similar pattern was noticed for the crucible steel sites, with all three crucible technology groups being geographically distinct. The assessment of smelting and crucible technology groups in relation to location setting also revealed variation between technologies. For example, smelting group 1, which is dominant in the region occurs in all location settings, whereas smelting group 2 are preferentially located in rural environs further from settlements. This was also noticed for crucible sites. Crucible groups 1 and 3 tend to be larger, more specialised sites located close to or within settlements, while the smaller crucible group 2 sites are more widespread throughout the landscape with a preference outside or on the edges of settlements.

Several reasons for this technological variation have been proposed. Different groups of people with their own metallurgical traditions may have operated in different areas, hence, idiosyncratic developments of localised ‘signature’ practices. The technologies themselves may have produced different end products or have been intentioned for different uses or consumers. It is also probable that there is a temporal dimension to the variations, with different technologies employed at different times. As a whole, interpretation, particularly the chronological variation in technology is limited by the lack of stratigraphic context and dating. However, the identification of different technological groupings means that future work (excavation and/or survey) can target sites with greater potential for providing dating evidence. Due to the large scale of the surveyed area and the longevity of Indian metallurgical traditions (chapter 2), variation in technology was expected and is likely to be the outcome of all three reasons discussed above.

The interrelationship of iron smelting and crucible steel was also assessed. Although different smelting technologies appear to have operated alongside the three crucible groups, no unusual or special metallurgical technology was in operation on these sites. The smelting activities are identical to the dominant smelting technological groups in their respective geographical areas; smelting groups 1 and 9 on crucible group 1 sites, smelting groups 1 and 1.1 on crucible group 2 sites and smelting group 8 on crucible group 3 sites.

This indicates that crucible steel production was part of the larger metallurgical tradition in Northern Telangana, and evidence for its longstanding manufacture in the area.

8 Scientific Analysis of the Crucibles

By comparison with analyses of ingots and related crucible steel artefacts, there have been few analyses of South Indian wootz crucibles. The published studies to date include, notably, those by Lowe (1989a; 1989b; *et al* 1991), and also by Rao *et al* (1970) and more recently by Balasubramaniam *et al* (2007) (see chapter 2.3.3). There is thus scope for further studies on this material to examine how it was manufactured and how it behaved in use. Although the studies above have given us a good understanding of microstructural character of examples of crucibles produced in Telangana, the issue is that they were often conducted in isolation from more detailed field and material morphological studies. Previous work selected only a few samples, for the most part taken out of their primary archaeological context. In addition, none of the publications have provided quantitative compositional data which could provide information on their production and use as well as add a dimension or tool for spatial and temporal (intra and inter-site) comparisons. The aim here is to provide detailed microstructural observations combined with quantitative compositional analyses in order to identify degrees of variation, between crucibles of the three types identified in this research (see chapter 6.2.6) both at site and intra-site level. However, it must be said that the lack of dating in this study will limit the extent as to which variation can be measured temporally but good spatial comparisons can be achieved.

The absence of any in-depth analysis of crucibles and crucible production in general in Telangana and other parts of South Asia has limited the value of previous comparative studies between the main production centres across Asia. Indeed, Rehren and Papakhristu (2000, 65) stress that “the full comparison of the Ferghana Process (Uzbekistan) to crucible steel making traditions elsewhere in Central and South Asia is considerably hampered by the very limited information available for the latter”. Therefore, as this study will enhance knowledge of crucible production in Telangana, the results and observations will be compared to other South and Central Asian crucible steel industries to identify any technological trends on a larger interregional scale.

To achieve this, a good representation of the three types of crucible and related material was initially selected for analysis. However, in the face of time constraints and machine availability, only 26 samples were analysed out of the 45 originally selected. Given the constraints, it was decided to focus on one material type, the crucibles, in the belief that they would reveal the most about the crucible steel manufacturing process. Only the more complete crucible body fragments were selected, with the majority of the lid fragments and the geological, green and black slag fragments not included (see chapter 4.3). Table 8.1 below shows the samples analysed with their site provenance and weight. It also highlights what kind of material they are made of and which of the main material layers composing the crucibles are present (exterior coarse coating, main body and black glassy slag – see chapter 4.3.1).

This chapter will be split into three sections. The first describes the crucible microstructures while the second will deal with the bulk elemental analyses. In the final section the results will be analysed and synthesised in a discussion. For ease of understanding, results and descriptions will be divided into the four main material types that constitute a crucible. These have been discussed in more detail under methodology (chapter 4.3.1) and material morphology (chapter 6.2.6). They include the coarse exterior coating, the main body, the interior black glassy slag and the lid. Each of these layers should reveal clues to crucible manufacture and use. The importance of considering all these material components is that no scientific study to date has analysed or discussed them in detail, preferring to focus instead on the fabric of main crucible body. The composition of the exterior coating layer is still a matter of debate (Balasubramaniam *et al* 2007; Lowe 1989a, 1989b; Srinivasan 2007, 680), while the composition of the lid and internal black glassy slag has yet to be fully investigated. The hope is that their investigation, combined with that of the main body fabric will give further insights on how these crucibles resisted high temperatures while the analysis of the black glassy slag may give clues about the raw ingredients (the charge) used to make wootz steel.

Table 8.1 - Material sampled, the location/site in which they were found as well as what material layers are present and their weight.

Smpl. No	Material Type	Location	Site	Comments	Ext layer	Main body	Glassy Slag	Weight (g)
1	C2	29/01/10 (1)	PM18	body	yes	yes	yes	58.9
2	C2	29/01/10 (1)	PM18	body + lid	yes	yes	no	81
3	C2	29/01/10 (4)	PM19	body + lid	yes	yes	yes	27.3
4	C2	29/01/10 (4)	PM19	body + lid	yes	yes	no	42
5	C2	06/02/10 (2)	PM54	body	yes	yes	yes	40.3
6	C2	06/02/10 (2)	PM54	body + lid	yes	yes	yes	67.5
7	C2	08/02/10 (9)	PM58	body	yes	yes	yes	56.8
9	C2	17/02/10 (2)	PM88	body	yes	yes	yes	33.6
10	C2	25/02/10 (1)	PM119	body + lid	yes	yes	yes	41.4
12	C2	26/02/10 (6)	PM128	body	yes	yes	yes	27.5
13	C2	26/02/10 (6)	PM128	body + lid	yes	yes	no	38.5
14	C1	09/02/10 (1)	PM60	body	yes	yes	yes	246.9
15	C1	09/02/10 (2)	PM60	body	yes	yes	Yes?	130.1
16	C1	09/02/10 (2)	PM60	body	yes	yes	yes	212.4
17	C1	09/02/10 (5)	PM62	body	yes	yes	yes	52
18	C1	09/02/10 (5)	PM62	body	yes	yes	yes	261.8
19	C1	09/02/10 (5)	PM62	body	no	yes	no	217.7
20	C1	10/02/10 (1)	PM65	body	yes	yes	yes	212.5
22	C1	10/02/10 (1)	PM65	body	yes	yes	Yes?	38.4
23	C1	10/02/10 (2)	PM65	body + lid	yes	yes	yes	275.9
24	C1	10/02/10 (4)	PM67	body	yes	yes	yes	40.6
26	C1	22/02/10 (1)	PM106	body	yes	yes	yes	35.1
27	C1	22/02/10 (1)	PM106	body	yes	yes	no	76.1
29	C3	12/02/10 (3)	PM75	body	yes	yes	yes	104
31	C3	12/02/10 (4)	PM75	body	yes	yes	yes	76.6
33	C3	21/02/10 (8)	PM103	body	yes	yes	Yes?	111.1

8.1 Microstructures

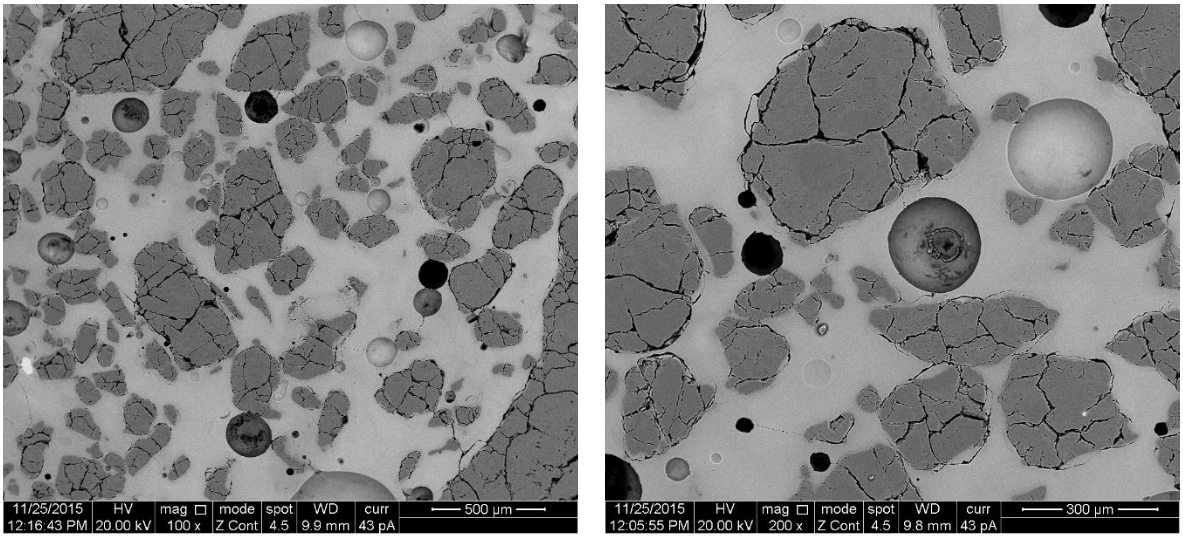
All the samples were analysed microstructurally as set out in chapter 4.3.3. A synthesised table of the microstructural observations is presented in appendix D.2. The main material layers constituting a crucible will be described here in separate sections.

8.1.1 Exterior Coarse Layer

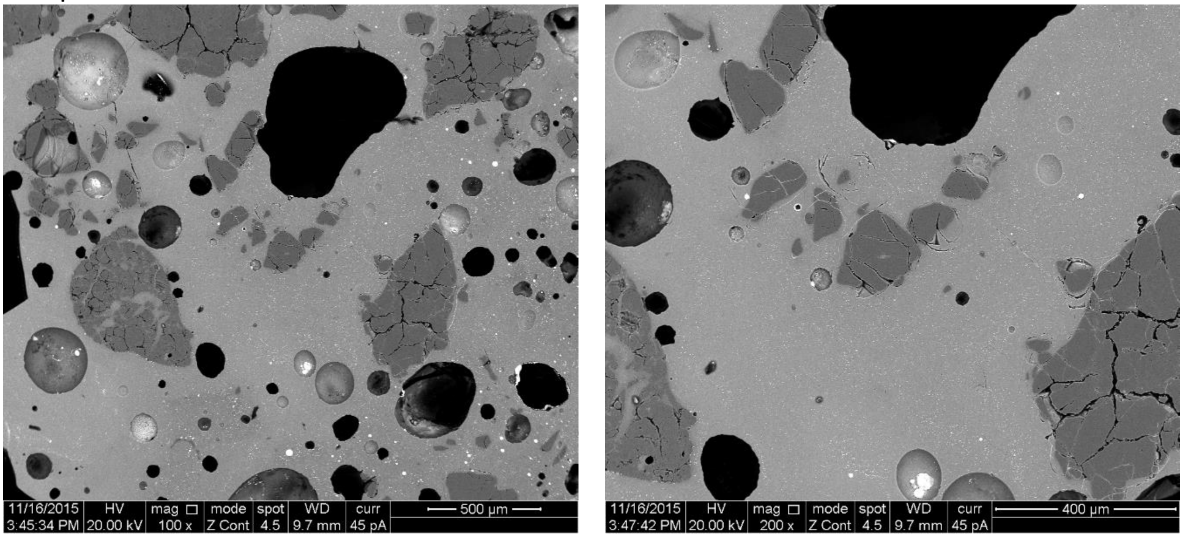
All samples examined have an exterior coating or layer of vitrified material which could reach as much as a centimetre thick. This layer has been discussed under material macro-morphology chapter 6.2.6. The only exception is sample 19, which appears to have not been used and hence not been covered with this external layer. All samples, regardless of crucible type and spatial distribution, appear to have similar external layer microstructures, primarily composed of large quartz crystals in a glassy matrix.

For the most part, this external vitrified layer is relatively solid with few voids, the porosity varying only slightly between samples. The few voids present are both open and closed pores. Most pores are spherical and <500µm in diameter but many samples also have slightly larger, more uneven globular voids <1mm. Voids up to several millimetre are not common but have been observed in a few examples.

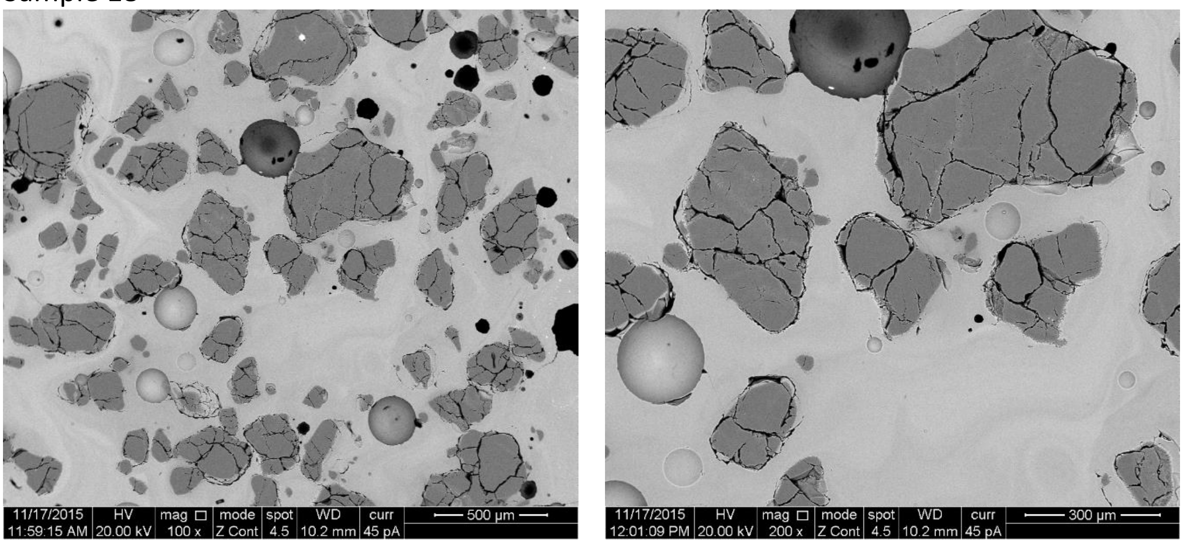
The material is dominated by large quartz crystals, mostly <700µm in size but as large as 4.1mm (Figure 8.1). These are pure silica in content and all examples are heavily cracked while some also appear to have partially melted. The larger crystals appear angular but the smaller examples have a more rounded profile suggesting that they may have partially melted. In some samples (particularly sample 29) some of these quartz crystals have started melting and recrystallising (forming smaller grains) on the periphery of larger crystals. This phenomenon appears to have been confined to areas close to the external surface of this layer probably because it was in more direct contact with the heat source. Since the melting temperature of quartz is of 1670˚C they attest to the high temperatures endured during the firing process.



Sample 5



Sample 18



Sample 29

Figure 8.1 - Dominance of quartz crystals (dark grey) within a glassy matrix (mid grey) in the crucible exterior layer. Left images 100x and right images 200x of same sample.

The glassy matrix in most samples is particularly homogenous with no visible microstructure (Figure 8.2) but there is slight variation between samples in the extent of vitrified/glassy areas between the large quartz crystals. This material layer appears glassier closer to the external edge. In some cases there are changes in shades visible in the backscattered electron SEM images (Figure 8.2) evidencing localised variation in chemical composition. Indeed, the compositional analyses have revealed variation mostly in SiO_2, Al_2O_5 and CaO content with darker areas having, for the most part, a lower CaO and higher SiO_2 or Al_2O_5 content. These darker patches are often around quartz crystals suggesting that their partial melting contributed to the glassy matrix melt.

All samples also show small iron prills in the glassy matrix (Figure 8.2). This is likely to be the result of the reduction of the iron oxide present in the clay and is proof of the highly reducing atmosphere achieved in the furnace hearth where the crucibles were heated. An interesting thought is how were these prills formed? Where they formed by the reducing atmosphere in the furnace (exterior of the crucible) or the reducing atmosphere in the interior of the crucible which may have leached through the crucible walls? This cannot be resolved within the scope of this study but could be assessed in future experiments. The abundance of the prills varies from sample to sample. Although all crucible types had a variation of iron prill content it is interesting to point out that, on the whole, there were less prills in the crucibles of type 2. This variation is more likely to have resulted from the different clays used as opposed to any difference in operation. It is possible that some clays in certain areas were less rich in iron oxide than others and that there was less to reduce to metallic iron. The majority of the prills present were <5μm in diameter and randomly precipitated within the glassy matrix (Figure 8.2) but in some samples there were a few as large as 130μm.

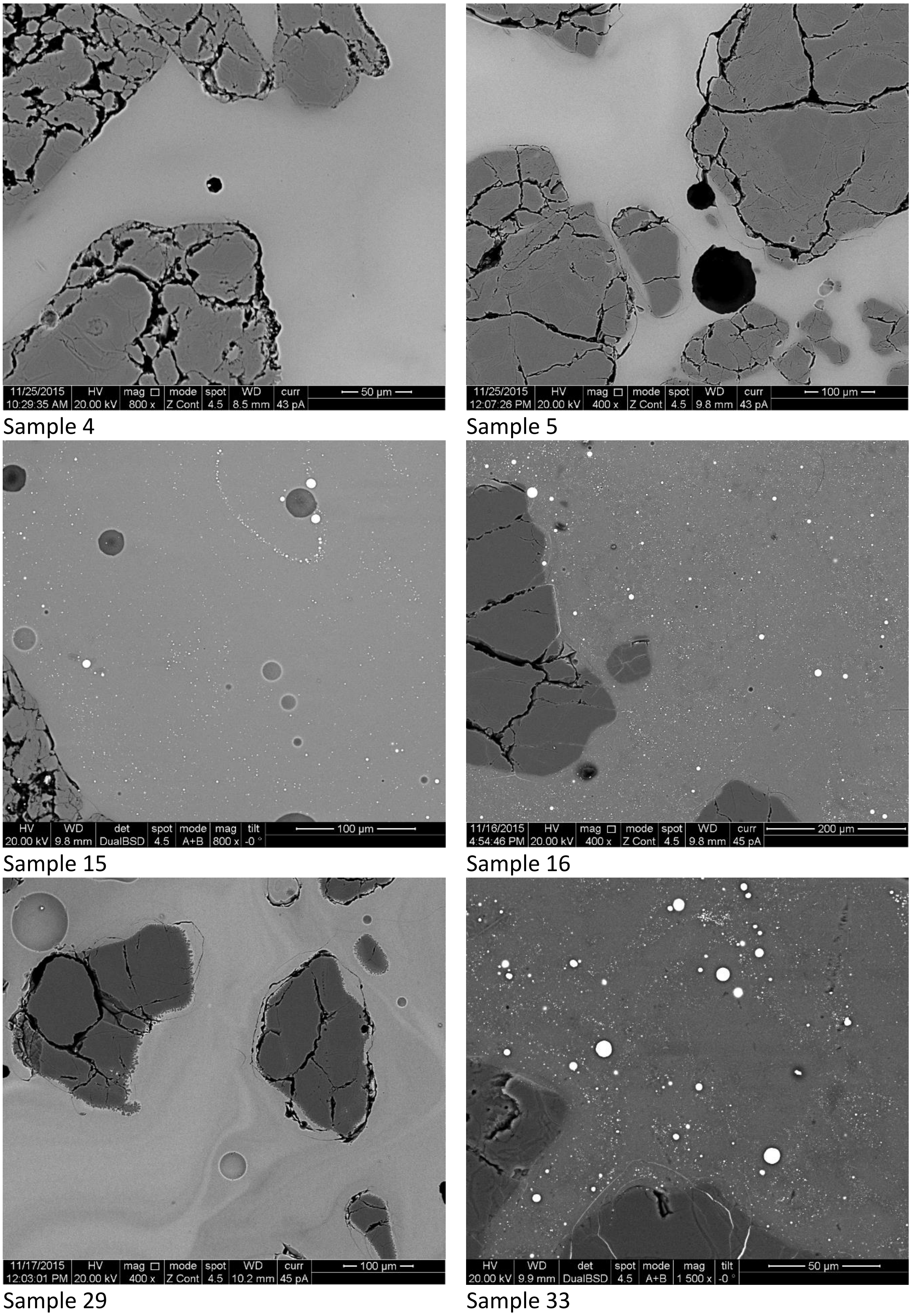
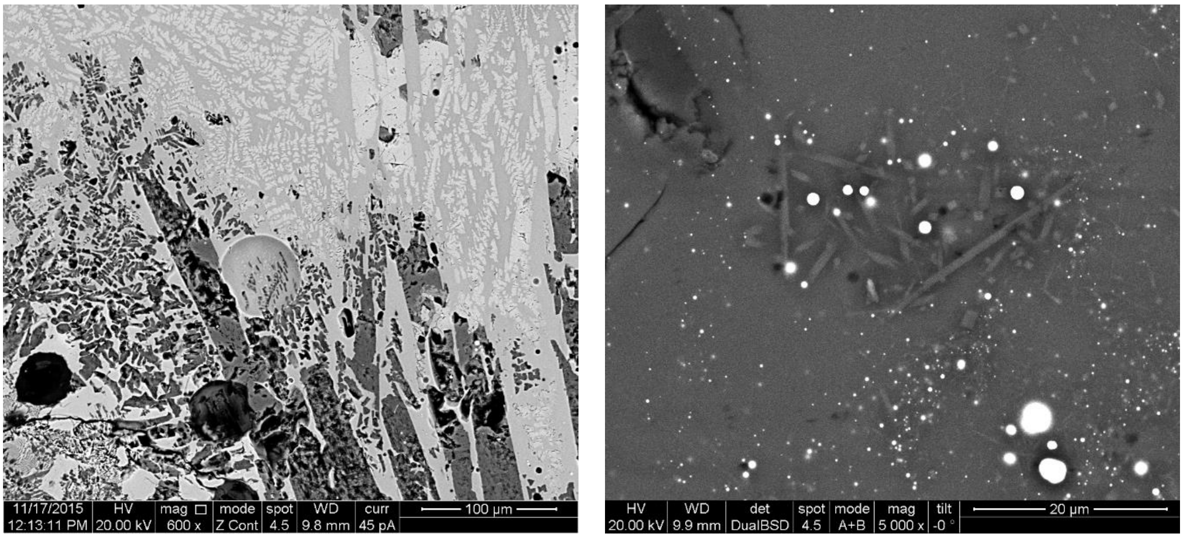


Figure 8.2 - Homogenous glassy matrix in the crucible exterior layer. Note randomly distributed small iron prills (white).

Two samples have distinctive features which need to be mentioned here. Sample 29 has as a lathy wollastonite ($CaSiO_3$) phase within the glassy matrix (Figure 8.3). These are up to 40µm in width and 1.2mm in length, concentrating on the exterior edge of the sample. Sample 33 also has some interesting features. In a few areas, very small needles, up to 1µm in width and 20µm in length, are found within the glassy matrix (Figure 8.3). These appear to agglomerate in concentrations less than 40µm in diameter. These features are however not the norm for the majority of the samples.



Sample 29 Sample 33

Figure 8.3 - Glassy matrix in the crucible exterior layer showing wollastonite laths in sample 29 (left) and small needle phase in sample 33 (right).

Of note is the boundary between the coarse exterior layer and the main body fabric of the crucible. In all samples this zone shows the two fabrics well fused together. Although the microstructures indicate that both fabrics are different, the glassy matrix of both merge almost seamlessly into one another (Figure 8.4). This attests to the high temperatures reached during the firing process and possibly the stability and prolonged duration of the firing.

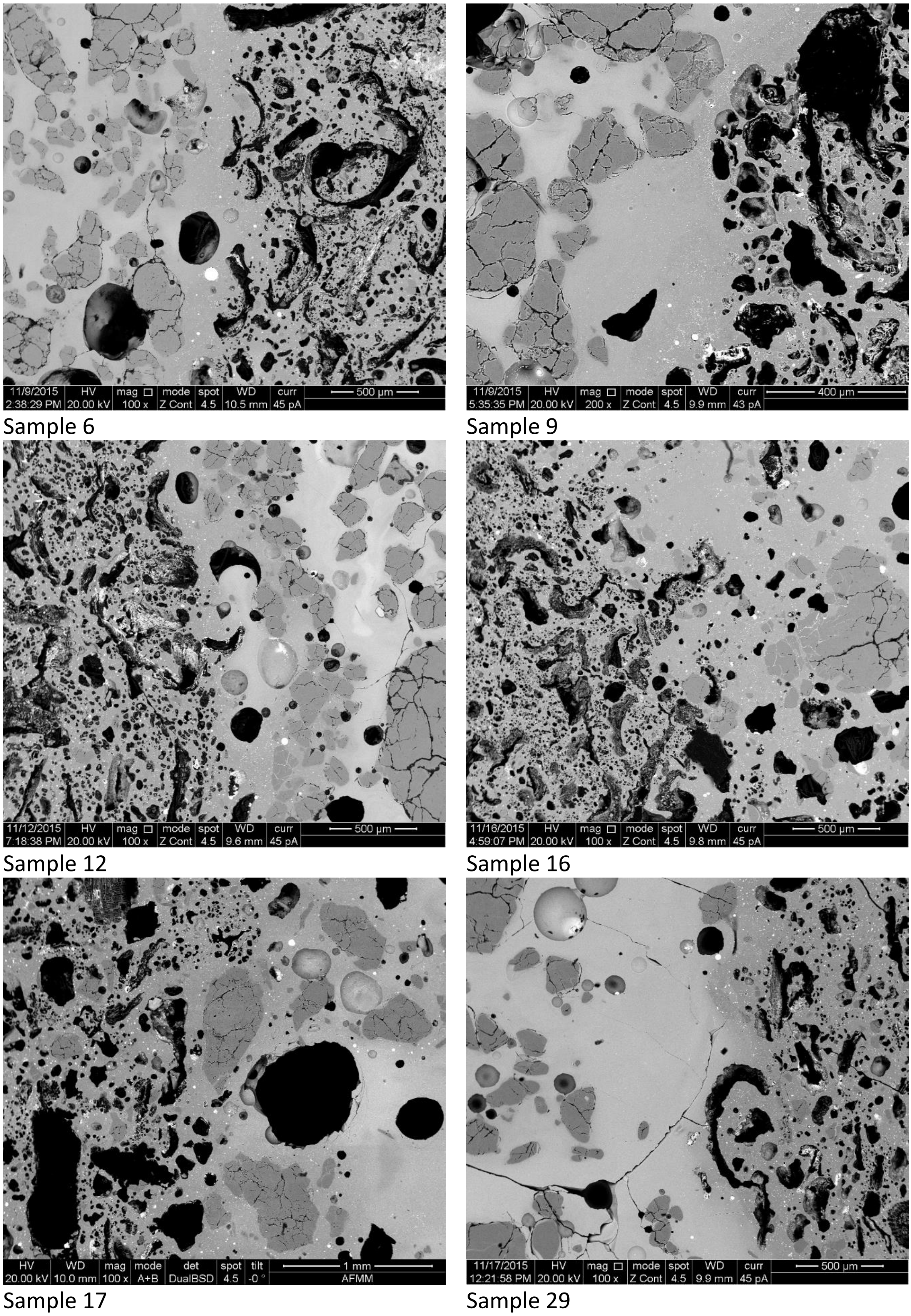
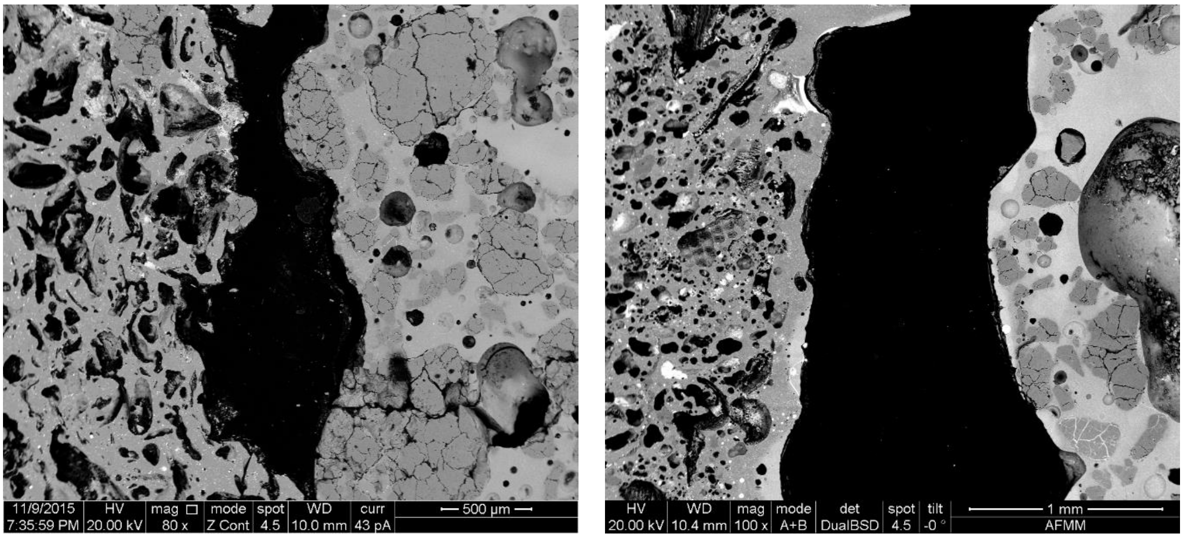


Figure 8.4 - Boundary zone between coarse exterior layer and main crucible body fabric. Note the smooth transition of the glassy matrix in all examples.

In some examples, parts of the boundary between the two fabrics are separated by large elongated voids following the contact zone (Figure 8.5). This was also noticed during the morphological examination, whereby the exterior layer appeared to have become almost separated from the main body of the crucible (chapter 6.2.6 and appendix C.6). However, this is not a consistent feature.



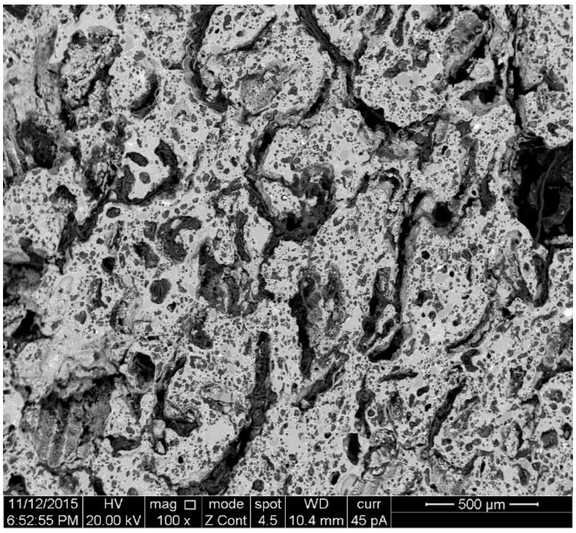
Sample 3 Sample 13

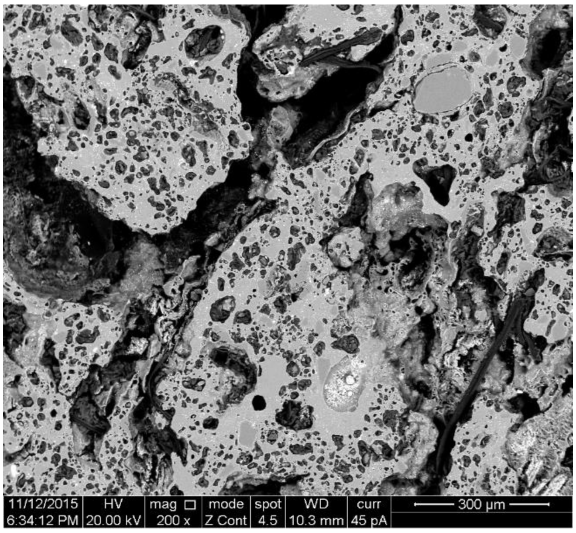
Figure 8.5 – Large, elongated voids along the boundary zone between the coarse exterior layer and main body fabrics.

8.1.2 Main Crucible Body

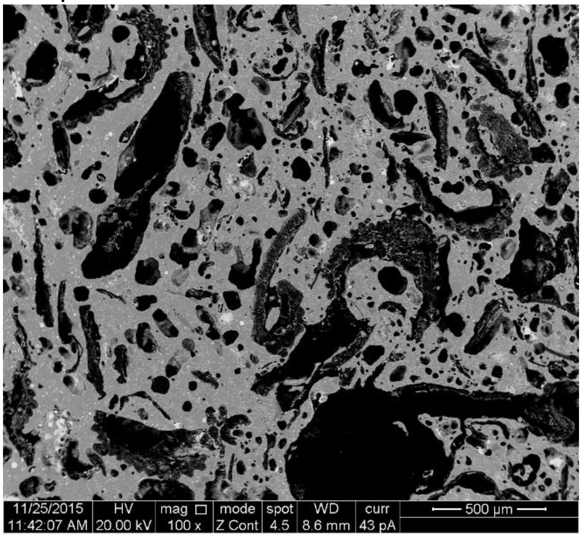
The main body of the crucibles has been the most analysed part of wootz crucibles in past studies. All samples selected for this study incorporate the main fabric. The width of this layer varies from a few millimetres in smaller examples to as much as 20mm in larger examples. The morphology of this material has been discussed in chapter 6.2.6. The main body fabric of the crucible has a distinct black colouration attributed to the high temperatures reached and extreme reducing conditions during the firing process. This material is characterised by the remains of rice husks in a mostly homogenous glassy matrix. The only exception is sample 19 which does not appear to have been subjected to such high temperatures (unused) allowing the more complex microstructural composition of the matrix to survive.

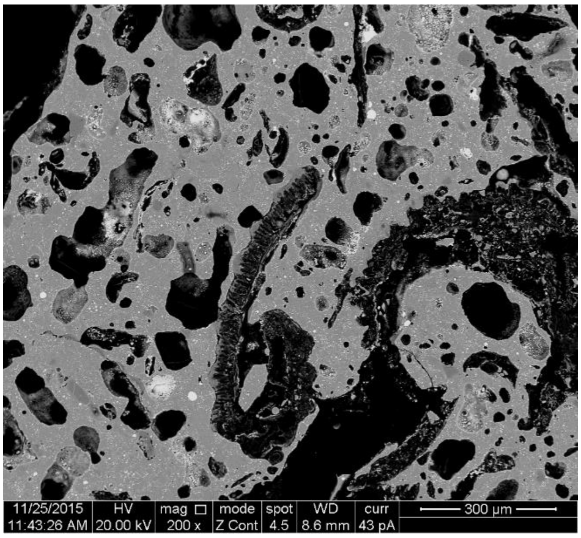
The most striking element of the main crucible body is the porosity and rice husk remnants (Figures 8.6 and 8.7). This porosity has been discussed in detail by Lowe (1989a; 1989b; Lowe *et al* 1991) and comprises two distinct types of void. The first are small spherical/globular pores, most probably formed by trapped gases (gas evolution) during the firing process, from the reduction of FeO to Fe metal. The second are larger, elongated (sometimes networked), irregular voids which appear to be formed by the relics of charred rice husks (Lowe 1989a, 736; 1989b, 241; Lowe *et al* 1991). Some of these elongated voids are slightly curly (reminiscent of a sickle moon) and were clearly created by organic inclusions which subsequently burnt during exposure to high temperatures. Although all samples examined in this study have very similar main body microstructures, the porosity levels and abundance of rice husk relics do vary slightly between them. This suggests that very similar raw materials (clay and rice husks) were used in the manufacture of the crucibles, regardless of morphological crucible type or geographical location. The proportions of each ingredient used may have differed slightly even within the same site due to the practice and idiosyncrasies of individual crucible makers.



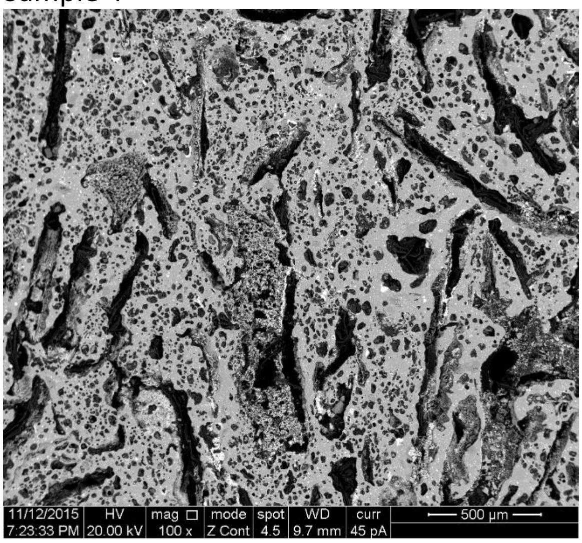


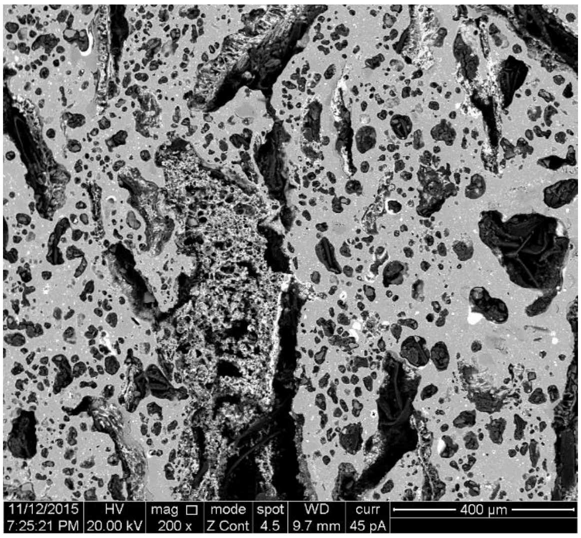
Sample 1





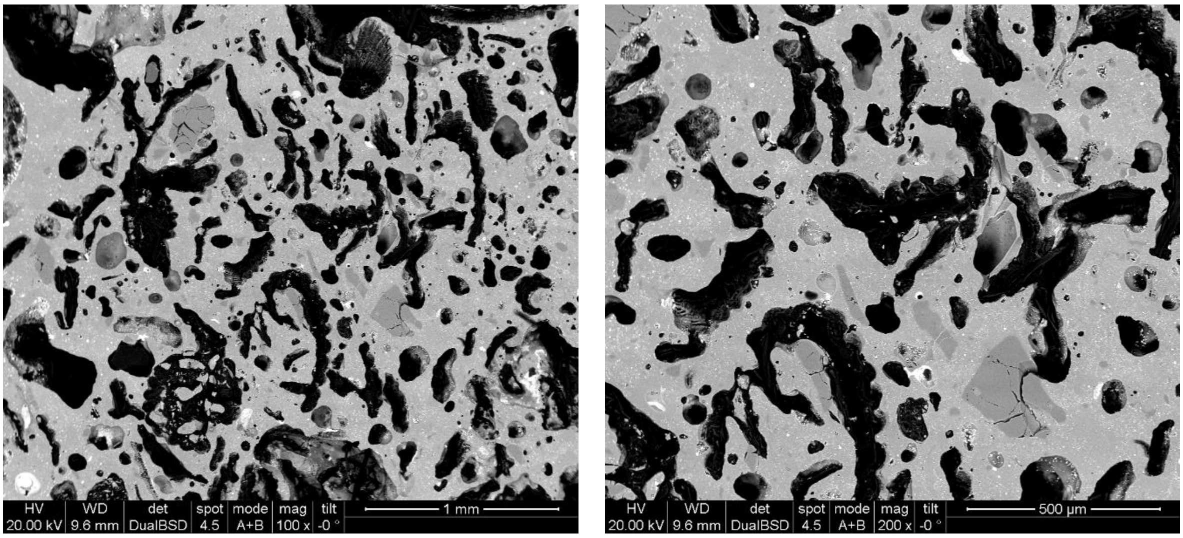
Sample 4



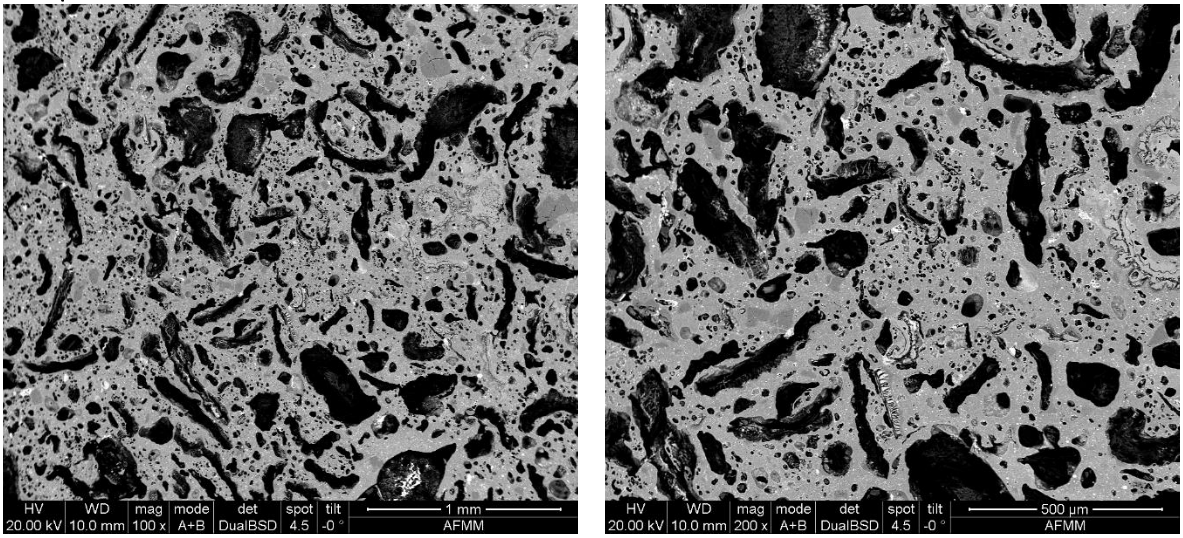


Sample 12

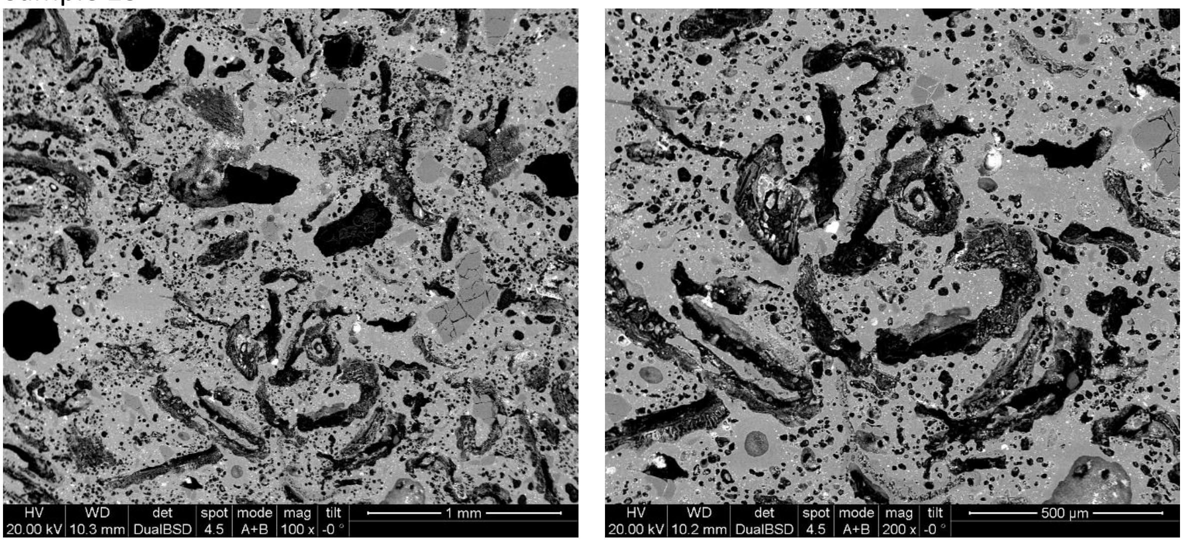
Figure 8.6 - Similarity in all crucible main body fabrics. Note the elongated rice husk remnants and spherical gas voids which vary slightly in abundance between samples. Left images 100x and right images 200x of same sample.



Sample 15



Sample 23

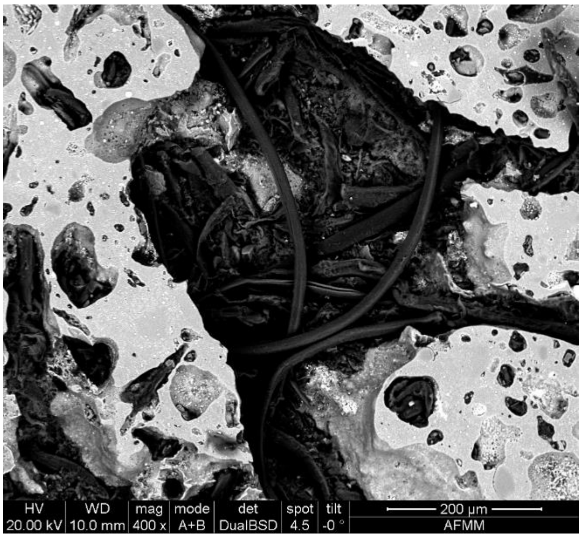


Sample 33

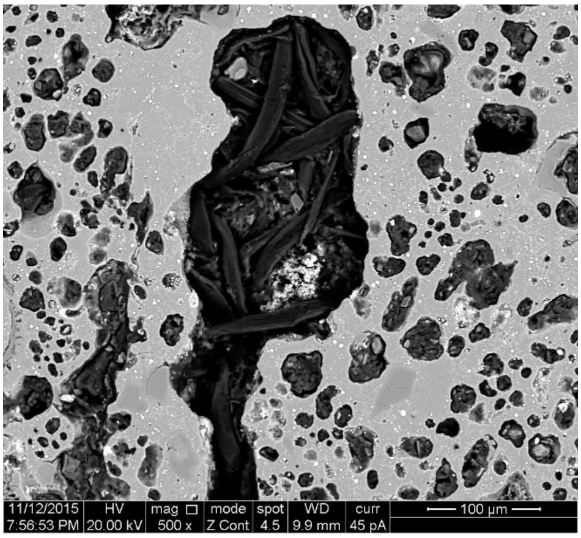
Figure 8.7 - Similarity in all crucible main body fabrics. Note the elongated rice husk remnants and spherical gas voids which vary slightly in abundance between samples. Left images 100x and right images 200x of same sample.

Voids and husk inclusions are present in different forms. Most of the small spherical or globular pores appear devoid of features (empty) appearing as black features on the SEM micrographs. On the other hand, the larger elongated voids often have what appears to be burnt organic matter within them. A common feature observed in all examples is the presence of dark cylindrical fibres curled within certain pores (Figure 8.8). These have been discussed by Balasubramaniam *et al* (2007), and Srinivasan (2007) in her analyses of other South Indian crucibles from the state of Tamil Nadu, but the authors are not in agreement over their composition and identification. Whereas Srinivasan (2007) identified them as SiC, Balasubramaniam (2007) describes them as graphite stems (pure C). The main issue with these fibres is their small size and location. Most are less than 30µm in width and nested in pores below the flat polished surface of the samples making it difficult to analyse their chemical compositions accurately. Nevertheless spot elemental analyses were attempted in this study.

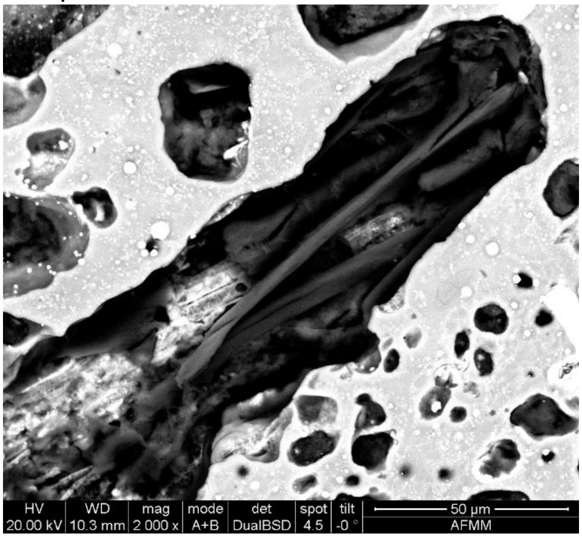
Two main fibre types seem to occur in each sample. Some appear to be curled within these elongated voids, often with a twisted body making their appearance less cylindrical and cracked. The other type appears more even with an almost continuous smooth cylindrical surface. However, the compositional results are not satisfactory enough to enable the identification of these stems. The most probable provenance of these fibres is proposed by Balasubramaniam *et al* (2007, 659-662) who suggest that they are the burnt remains of rice husk tails as their general size and shape conforms to the former. It is also possible that some of the fibres were acquired as a consequence of sample preparation. It was noticed that the polishing cloth fibres often became detached during polishing and may have lodged themselves within some of the larger pores. The identification of these stems or fibres will have to be resolved in future studies.



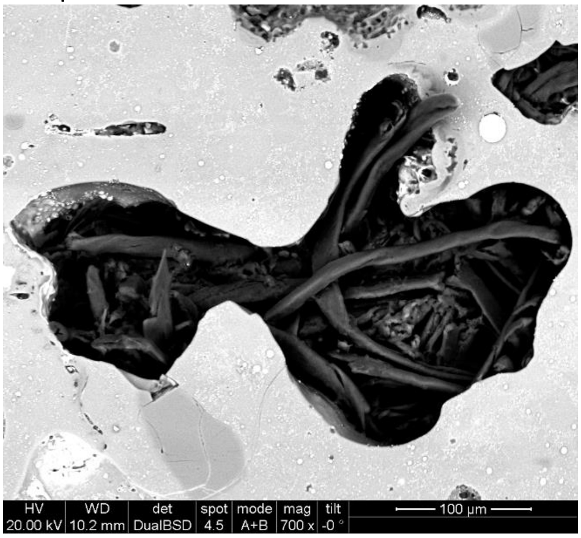
Sample 2



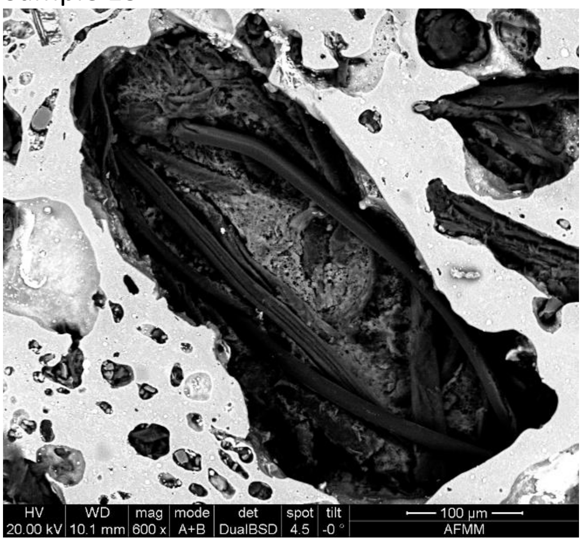
Sample 12



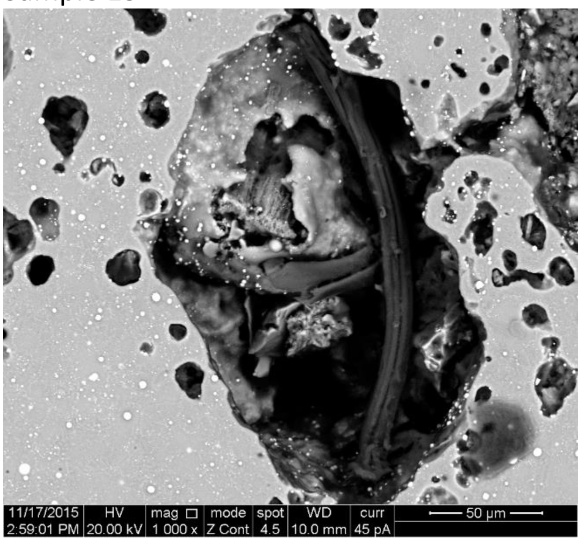
Sample 13



Sample 15



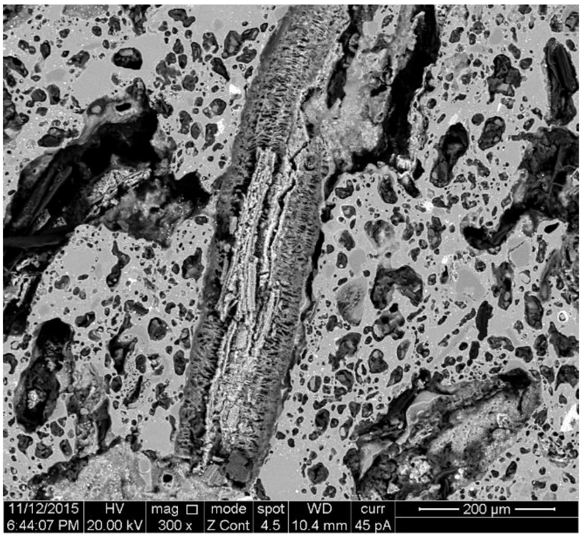
Sample 23



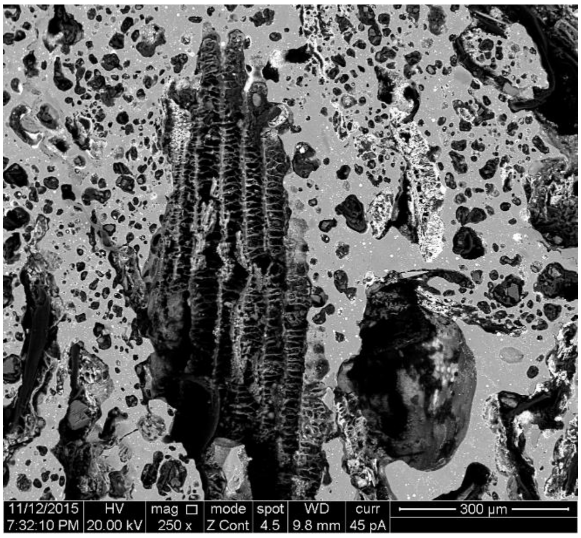
Sample 31

Figure 8.8 - Dark stems found in some of the elongated voids within the main body fabric. Note the twisted appearance of some of these stems while others are smoother.

The majority of the rice husk remains are in the form of amorphous material adhering to the edges of larger voids and crumpled fragments within the glassy matrix, however, in all samples there are well preserved examples with a basket-weave (checkerboard or honeycomb) texture (Figure 8.9). These have also been identified in previous microstructural studies (Balasubramaniam *et al* 2007, 663; Lowe 1989a, 736-7; 1989b, 244; Lowe *et al* 1991). Several small bulk analyses were taken for this study and the results are in accordance with those observed by Balasubramaniam *et al* (2007, 663). These basket-weave regions are almost pure silica but also contain small proportions of MgO, Al_2O_3, K_2O, CaO, TiO_2 and FeO. The CaO, TiO_2 and FeO content probably resulting from the inorganic portion of rice husks (Balasubramaniam *et al* 2007, 663). Both Lowe *et al* (1991) and Balasubramaniam *et al* (2007, 663) suggest that the SiO_2 content in these is present in cristobalite crystalline form but this could not be confirmed in this study.



Sample 1



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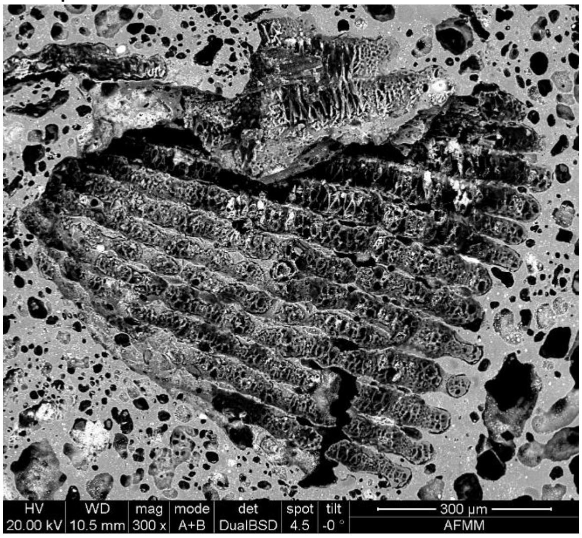

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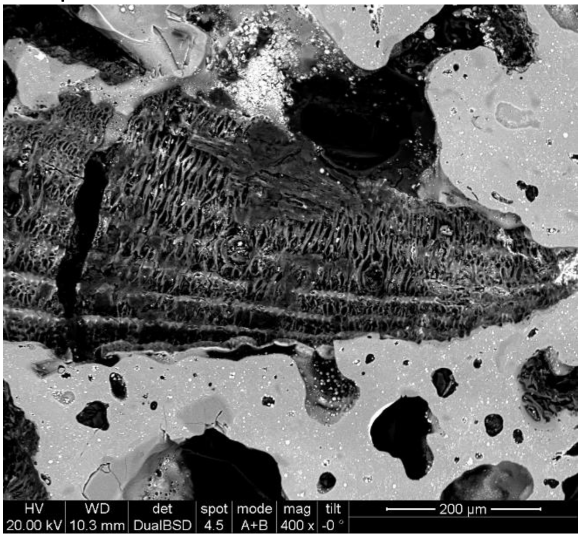

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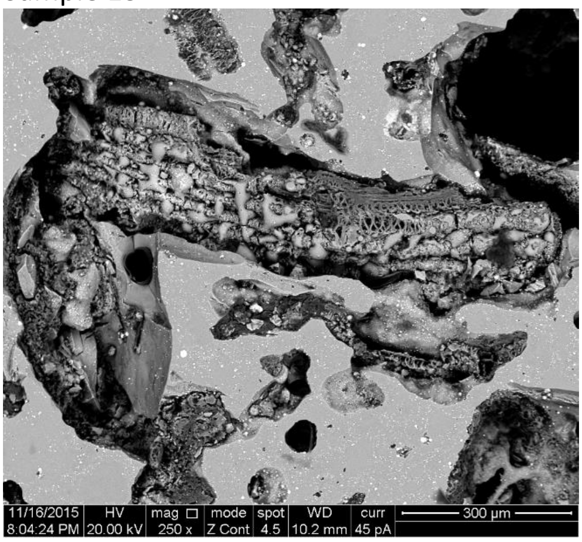
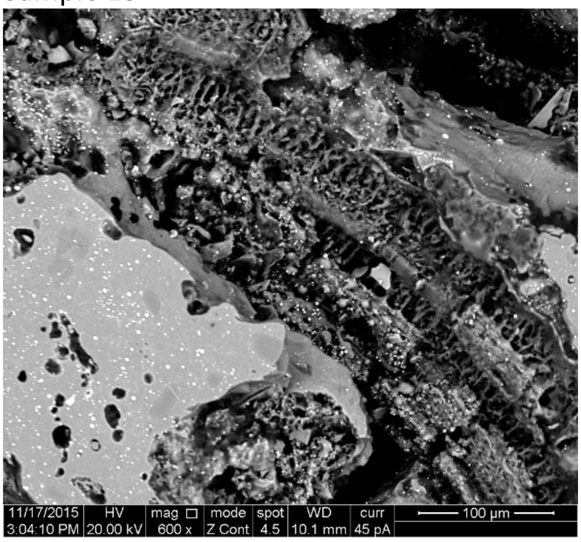


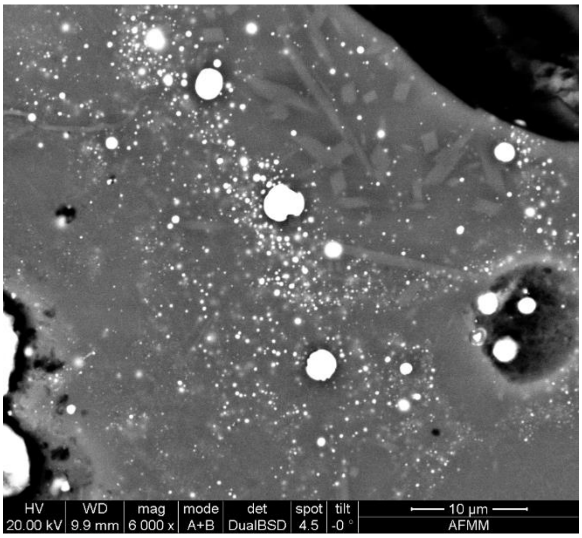
Sample 24



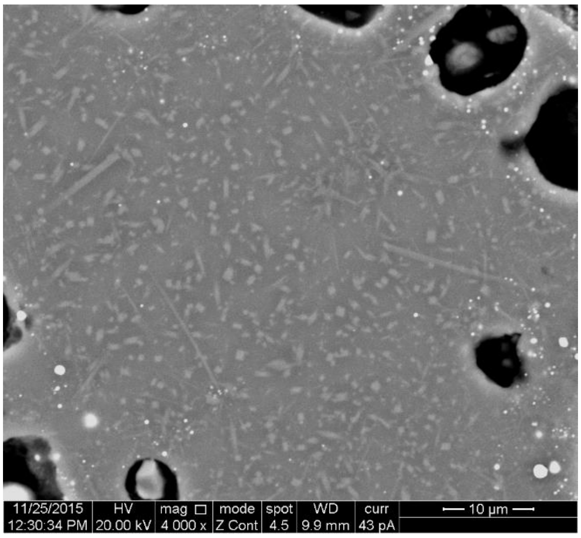
Sample 31

Figure 8.9 - Rice husk remnants found in the main body of the crucible fabric. Note their honeycomb or basket-weave appearance.

The glassy matrix of the main crucible body is also similar in all samples analysed. This glassy phase is dominated by dense concentrations of very small acicular mullite crystals ($3Al_2O_32SiO_2$). Individually these are mostly <2µm wide and <20µm in length but tend to concentrate in small agglomerations within the glassy phase, itself mostly Si in composition (Figure 8.10). As proposed by Lowe *et al* (1991), the mullite crystals (aluminium-silicate) most probably formed from the reaction of feldspar grains and finer crystallites commonly found in the clays. In addition, all matrixes contain frequent iron prills uniformly scattered through the glassy phase. These spherical prills are mostly <10µm but all examples also have few larger prills up to 100µm. These probably formed from the reduction of the iron oxide, which is naturally present in soils and clays, in the high carbon atmosphere created in the furnaces or excess carbon present in rice hull ash within the crucible fabrics (Lowe 1989b 241-3). An observation which deserves mention is that although these prills are found throughout the glassy phase they are less abundant to absent in localised areas where there are dense concentrations of mullite (Figure 8.10).

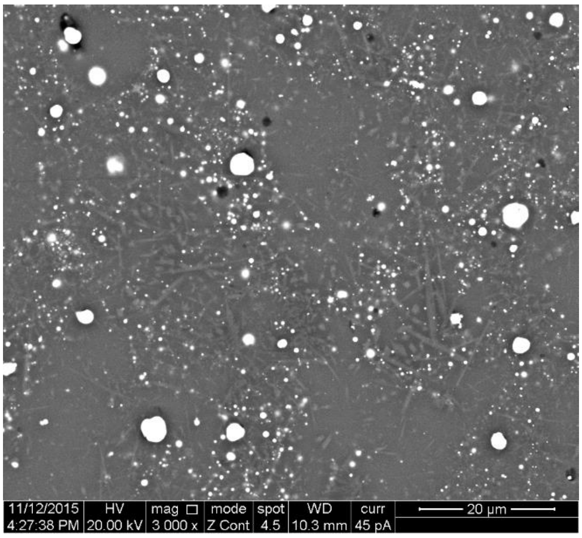


Sample 2

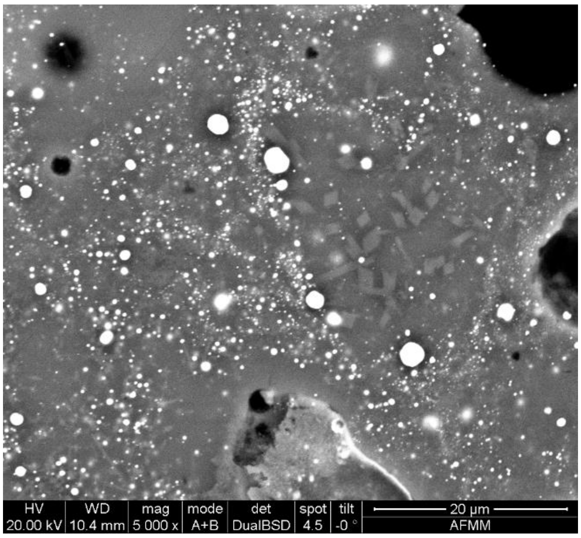


Sample 5

Figure 8.10 – see below



Sample 10



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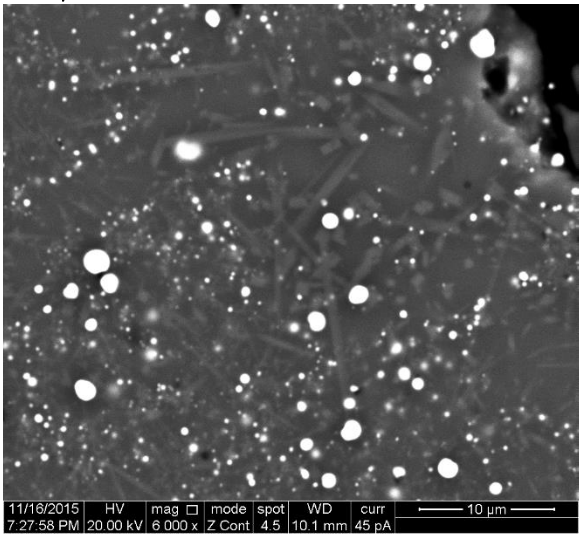

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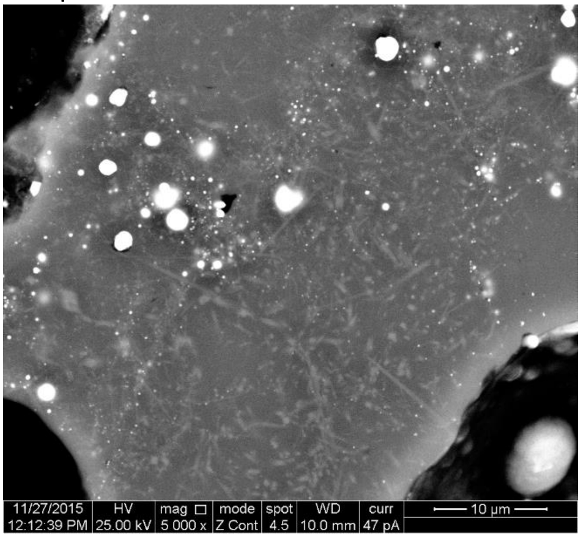
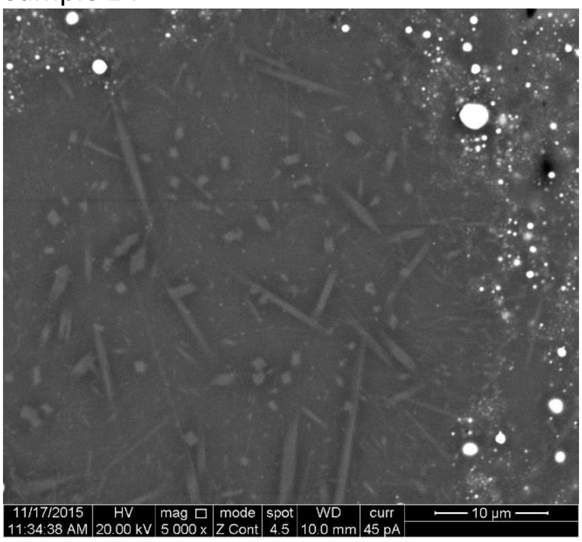
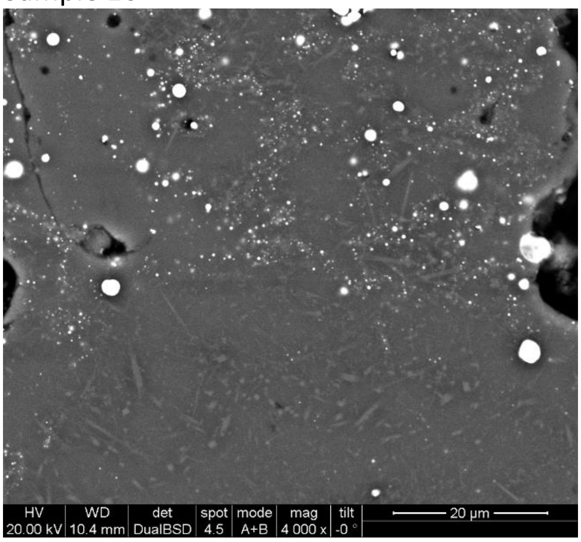


Sample 26



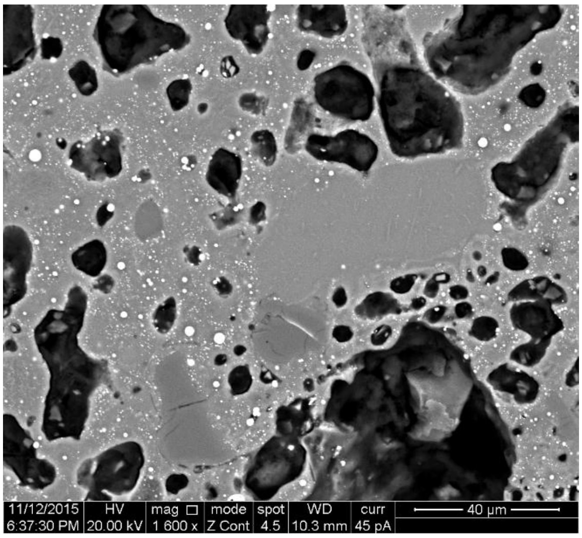
Sample 27



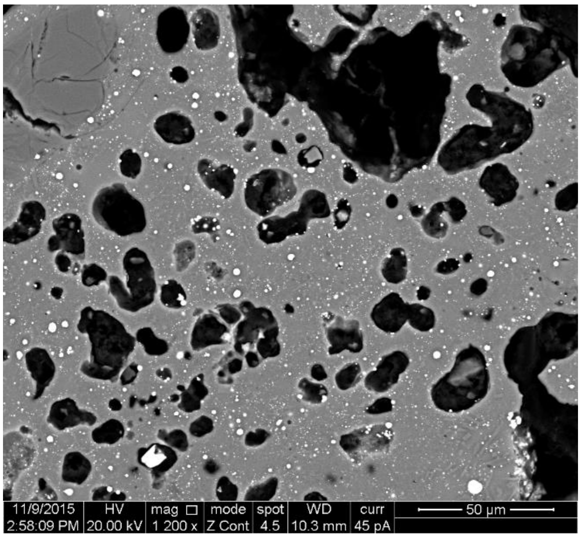
Sample 33

Figure 8.10 - Glassy matrix within the main body of the crucible fabric. Note the very small mullite needle concentrations that dominate and the more sparse iron prill presence in those areas.

Another common microstructural phase present in the main body of the crucible is quartz (Figure 8.11). All samples have some Si grains embedded in the glassy phase. The quartz content varies slightly between samples but they remain very few, suggesting that the soil or clay used was deliberately chosen for its fine structure and lack of quartz. In some examples (samples 16, 17, 18, 20, 22, 26, 29, 31 and 33), there are a few large quartz crystals up to 1mm but mostly <500µm in size. Similar to the quartz present in the exterior layer (discussed above) these crystals are often cracked and appear slightly rounded or melted on the edges (reaction rims). Of particular interest is that, on the whole, there appears to be more quartz in crucibles of type 1 and 3. The majority of the Si grains however, are very small, mostly <200µm in size, scattered randomly within the glassy phase (Figure 8.11). These do not appear to be cracked and are homogenous in nature with well rounded edges. Previous research has discussed the presence of these but there is no agreement as to their crystalline form or provenance. Lowe *et al* (1991) suggests that they are cristobalite while Balasubramaniam *et al* (2007, 658) believe that the crucibles were cooled too fast to enable a stable Si crystalline form to remain, believing instead that the majority of the Si content is amorphous.

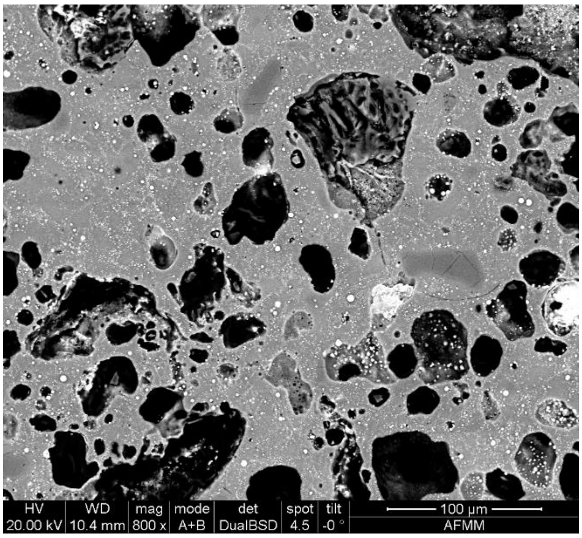


Sample 1

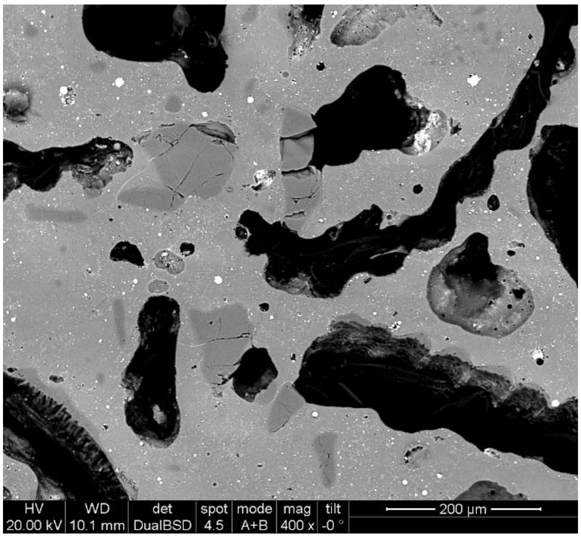


Sample 6

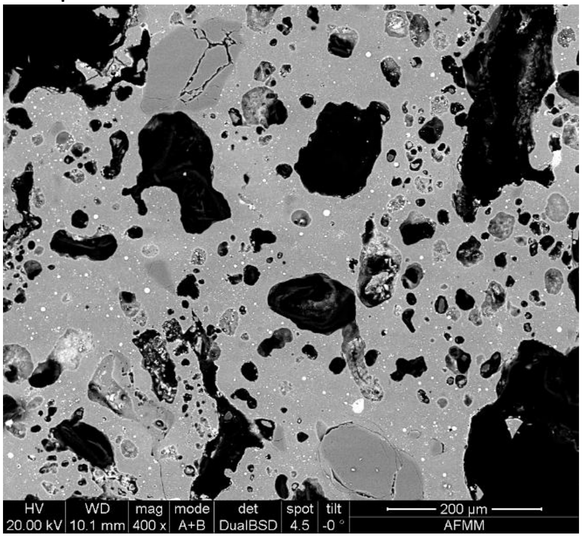
Figure 8.11 – see below



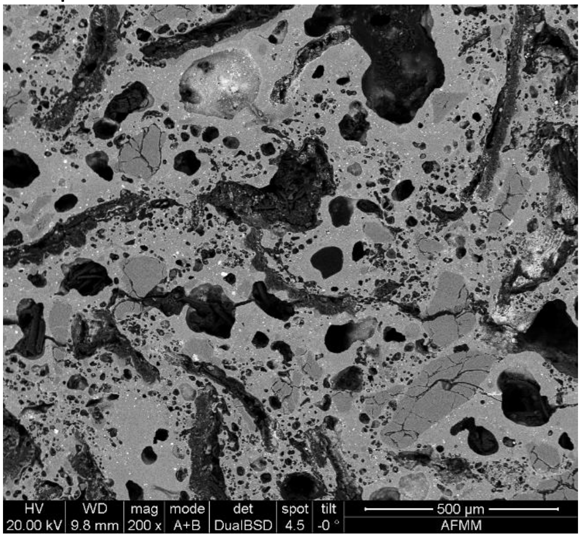
Sample 13



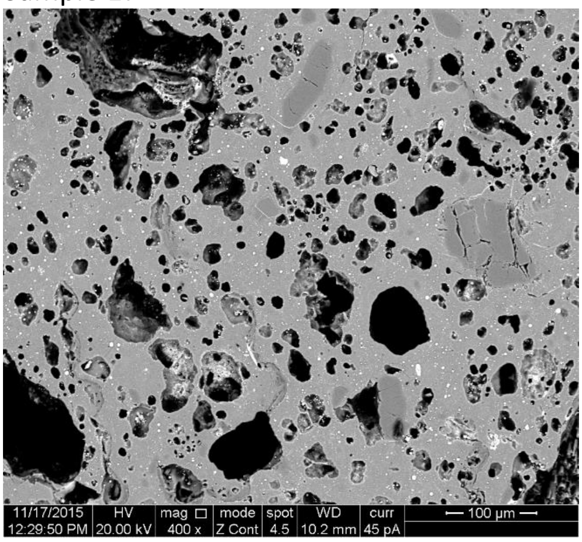
Sample 15



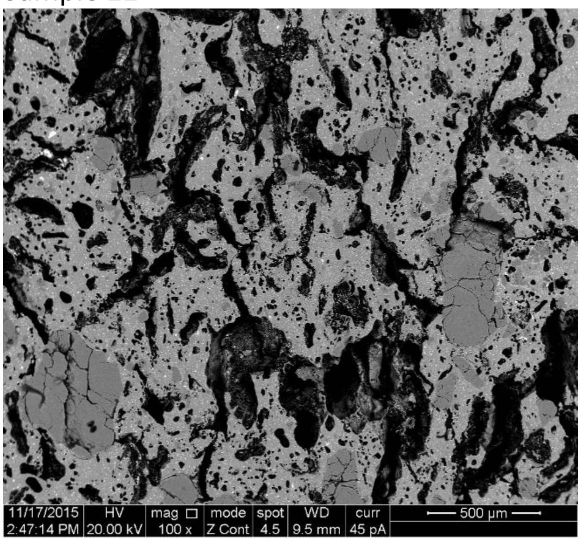
Sample 17



Sample 22



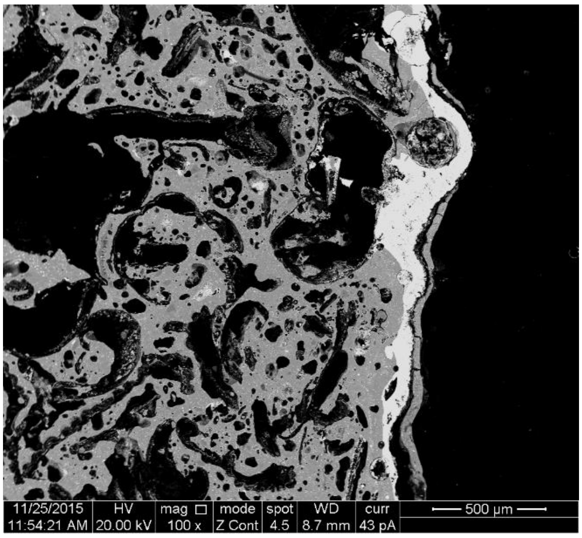
Sample 29



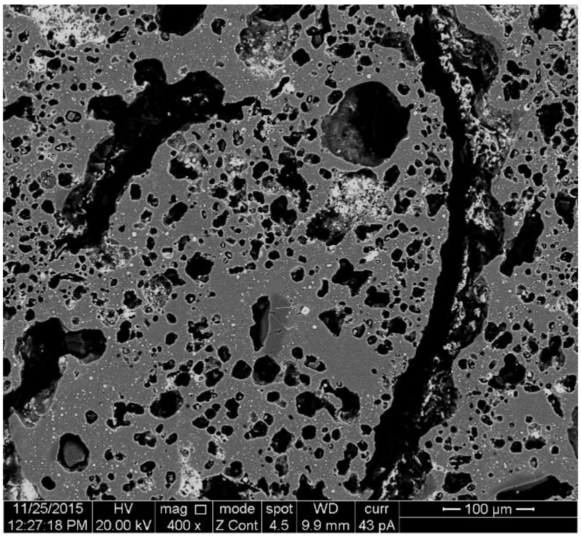
Sample 31

Figure 8.11 - Main body of the crucible fabric. Note the sparse quartz crystals (mid grey) randomly spread throughout the fabric.

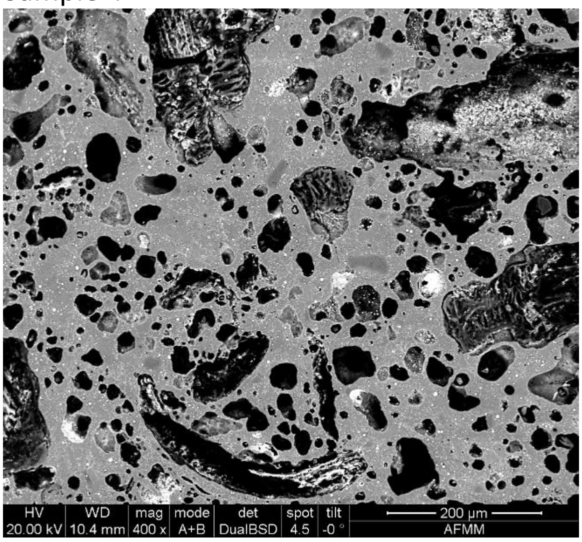
Another common feature of the main crucible body fabric is the presence of small bright areas occurring on the edges of voids or on the interior surface of most samples analysed (Figure 8.12). The analysis of some of these reveal that they are iron oxide rich regions. These do not appear to have any oxide form but are present as an amorphous oxide. They will from here on end be referred to as 'iron wash'. Their presence and origin is not certain as they have not been discussed in previous studies. Those found on the interior surface of the body fabric (Figure 8.12) could be oxidised iron from the charge but those within the body are a bit more puzzling. It may be that the trapped gas in the voids prevented the surrounding iron oxide present in the clay matrix to reduce to metallic iron. Another possibility is that these features were created post sample preparation whereby some iron rich areas corroded after being subjected to water and oxygen.



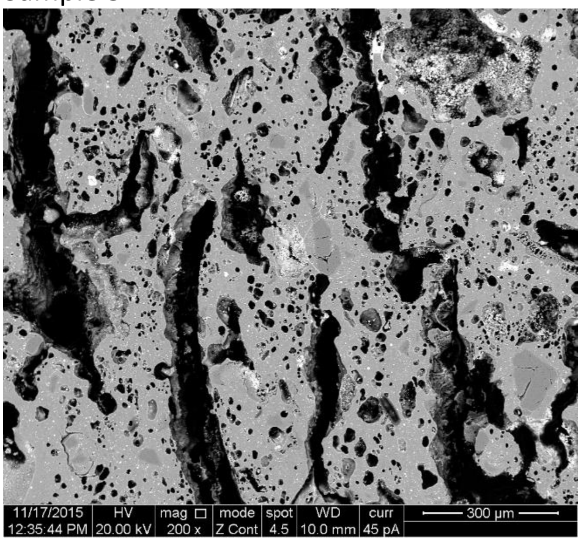
Sample 4



Sample 5



Sample 13



Sample 29

Figure 8.12 - Crucible main body fabrics. Note the bright iron oxide wash areas (white). Inner edge iron oxide can be seen in sample 4 (top left) and random bright splashes in samples 5, 13 and 29.

8.1.2.1 Unused Crucible

One sample deserves discussion. Sample 19 is an unused crucible. The microstructure is very similar to all other samples with the exception of the matrix which in this case is not glassy but crystallised. The fabric is also porous but unlike the vitrified examples, the voids are not spherical or globular but elongated thin cracks dividing the matrix and joining larger pores to one another (Figure 8.13). Similar to other samples, sectioned rice husks are visible by their honeycomb or basket-weave structure (Figure 8.13). A few large quartz crystals, up to 500µm, are also present but they are not cracked and do not have reaction rims. The matrix consists of very small Si grains (SiO_2 – dark grey) and feldspar ($KalSi_3O_8$ – light grey) crystals, mostly <50µm in size. These lie within an amorphous background which must undoubtedly be the silty (perhaps organic and other clay minerals) fraction of the clay used. Note also very few iron prills are present, suggesting that the iron is diffused in oxide form within the bulk of the matrix. Two features of interest were observed. A hammerscale flake present as a large rectangular iron oxide feature, measuring approximately 160µm in length and 25µm in width, and a small slag fragment comprising dendritic wüstite (FeO) and fayalite (Fe_2SiO_4) (Figure 8.13). However, these were not the norm and only singular examples were observed suggesting that they were accidental inclusions picked up during the manufacture of the crucible.

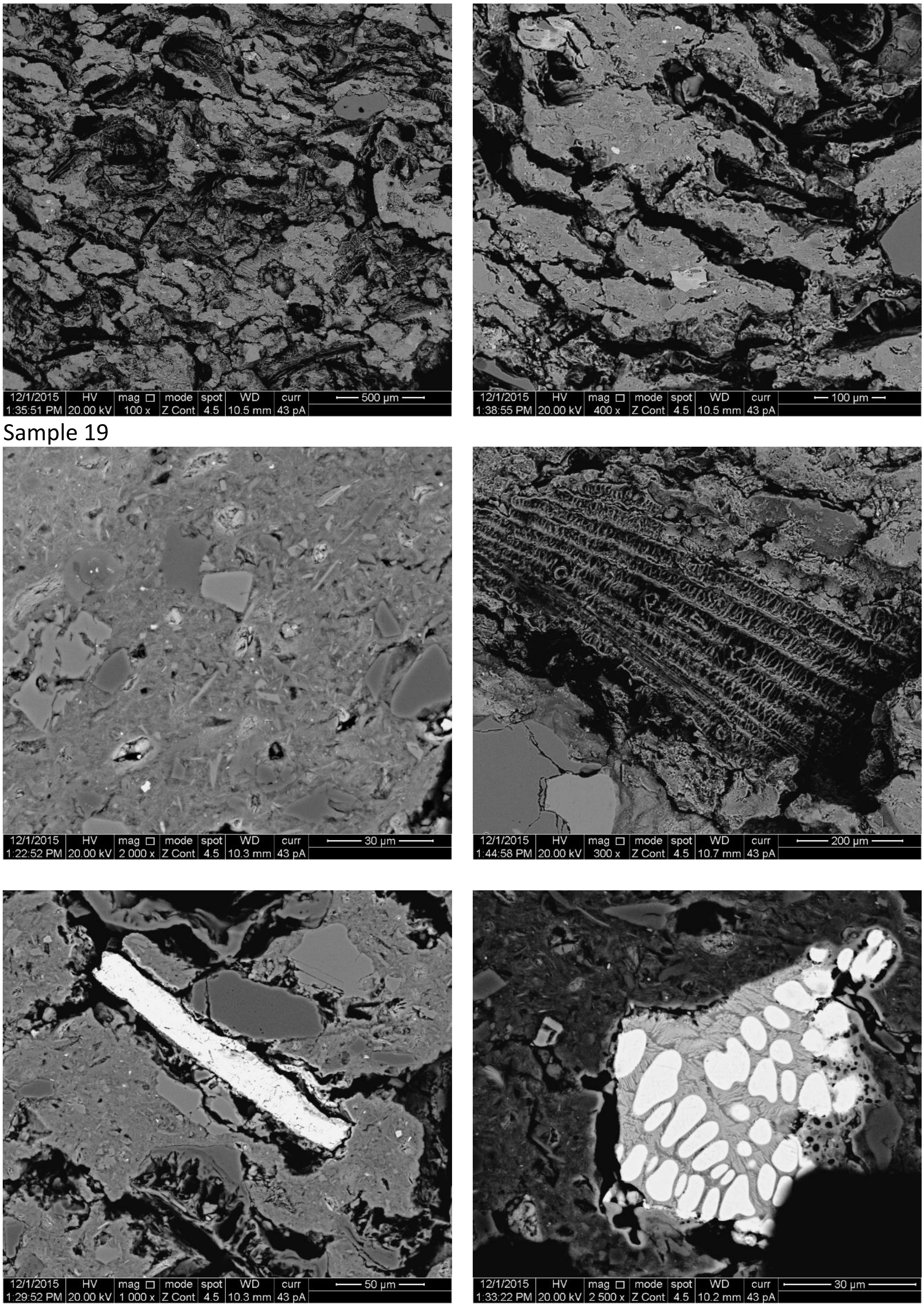


Figure 8.13 - Sample 19 crucible main body fabric (top images). Note the crystallised glassy matrix (centre left) and basket-weave structure of a rice husk remnant (centre right). Bottom left is a hammerscale flake while a small slag inclusion can be seen bottom right with wüstite (white) and fayalite (light grey) phases.

8.1.3 Internal Glassy Slag

Glassy slag was present on the interior surfaces of most crucible fragments in the assemblage but on a few samples (2, 4, 13, 19 and 27) the glassy slag layer could not be sampled either due to its thinness or its brittle nature, causing it to chip off during cutting. This layer varies greatly in thickness from <100µm to 7mm. In some cases the glassy fin described in chapter 6.2.6 was sectioned and this is where the glass is at its thickest (Figure 8.14). The majority of samples have a very homogenous glassy slag with no evident microstructure. Most are solid but spherical gas voids are present in some, up to 500µm (Figure 8.14). There is no major reaction with the wall of the crucible, with clear separation between the layers. However, the glassy matrix of the crucible in some examples seems to merge with the glassy slag. Samples 15, 22 and 33 have very thin glassy surfaces on the interior surface of the crucible wall (<800µm), making it unclear whether it is glassy slag or wall vitrification.

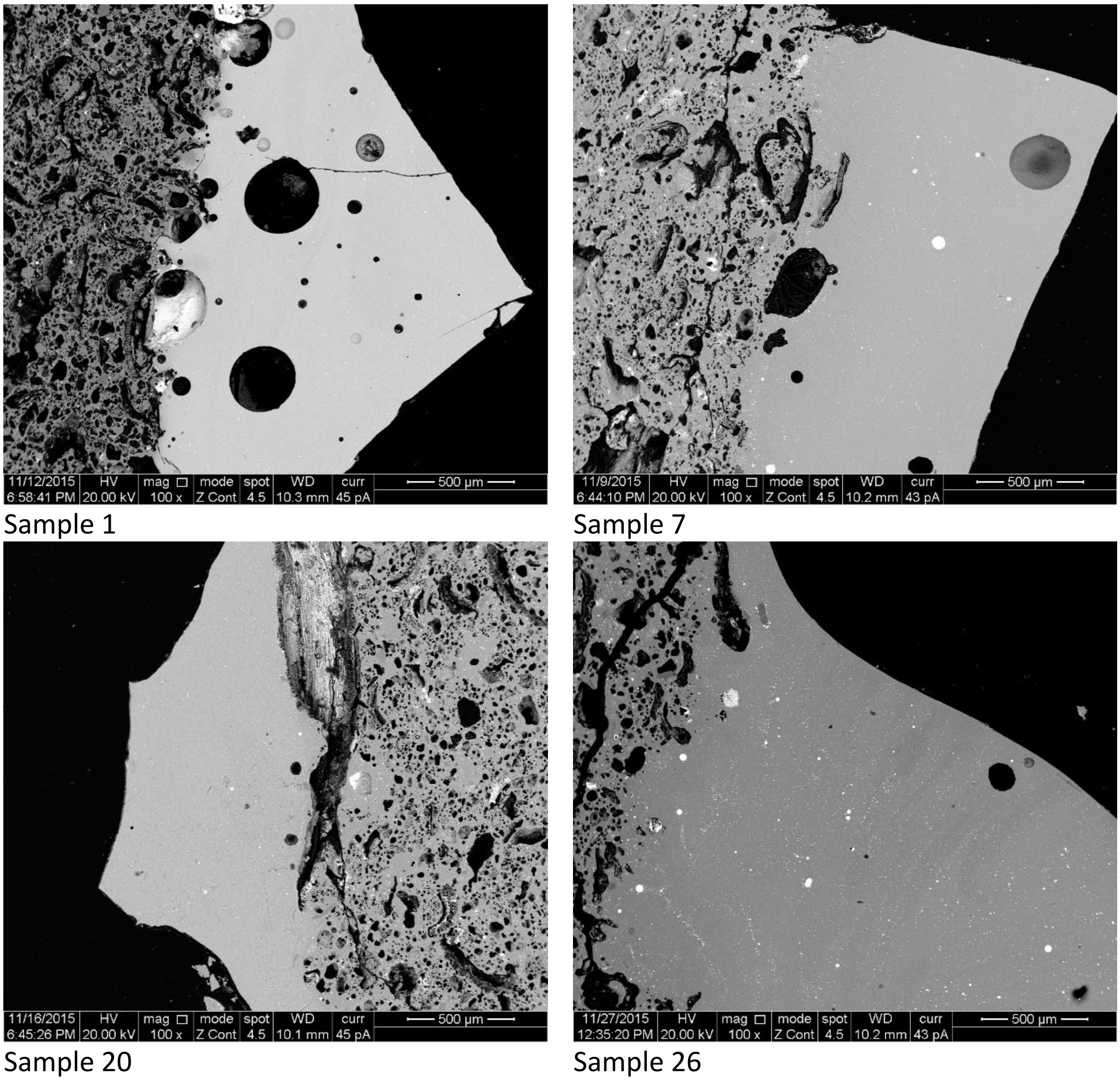
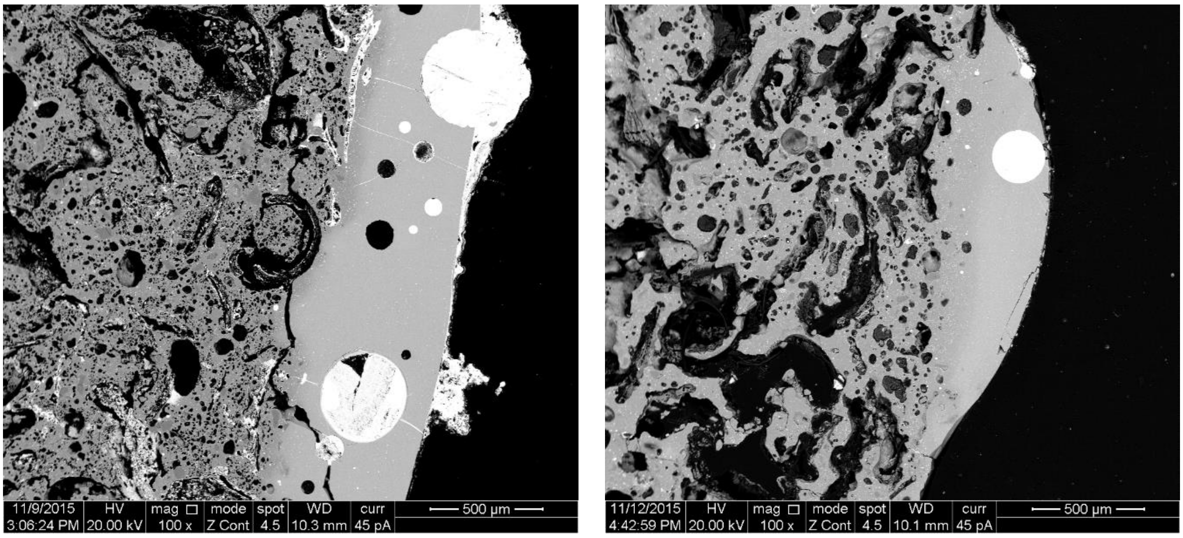


Figure 8.14 - Glassy slag in the interior of the crucibles. Note their homogenous and relatively solid nature.

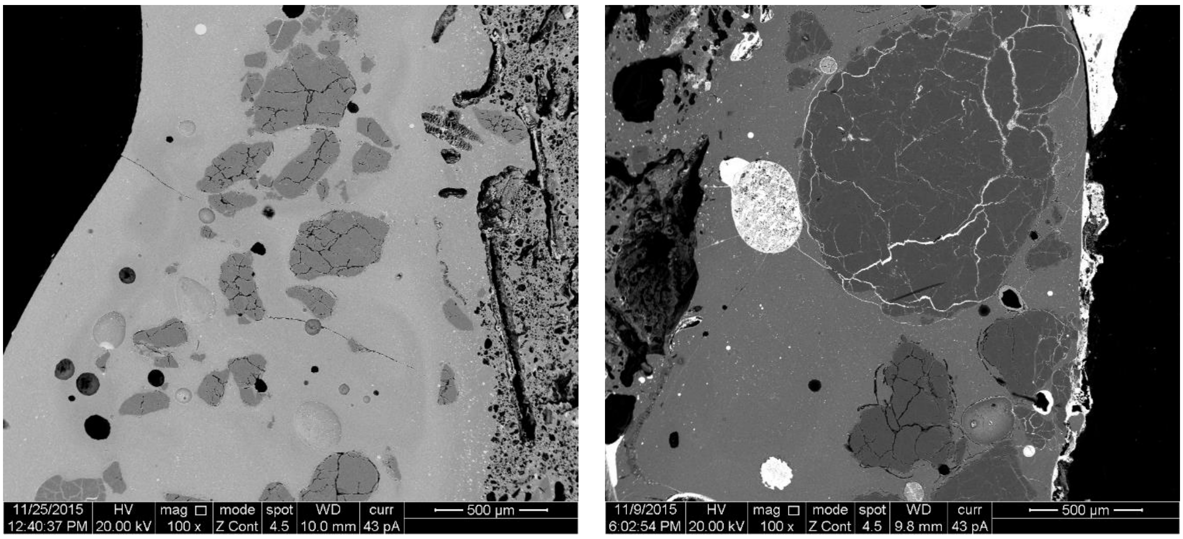
All examples also have small iron prills randomly distributed within this glassy slag. The abundance of these vary from sample to sample but again testifies to the reducing conditions created within the crucibles. Most prills are <10µm in size but larger ones up to 100µm are not uncommon. In a few samples (most notably 6, 9, 10, 12, 18 and 24) prills as large as 460µm are present (Figure 8.15) and could be the remains of the steel ingot manufactured within these crucibles. Some of these larger prills were analysed compositionally and revealed that the majority are pure iron, however, in a few instances there were traces of SiO_2, Al_2O_3, P_2O_5 and V_2O_5. Some samples (most notably 6, 9, 12, 14 and 22) also have some amorphous iron oxide ‘wash’ on the interior edge which is undoubtedly the corrosion (oxidisation) of iron rich areas.



Sample 6 Sample 10

Figure 8.15 - Glassy slag in the interior of the crucibles. Note the large metallic prills (white) in samples 6 and 10.

Fractured quartz crystals were present in the glassy slag of samples 5, 9, 12 and 16. These are for the most part <800µm in size but there are some as large as 1.3mm in sample 9 (Figure 8.16). The presence of quartz crystals within the glassy slag is interesting since they are not present in all samples. There are two main possibilities to explain their presence. It is possible that sand was added to the crucible charge as a silica flux, but the lack of quartz in most samples means that this is unlikely. Another possibility is that the quartz-rich lid fabric (discussed below) partially melted therefore entering and mixing with the crucible charge or at least the slag waste.



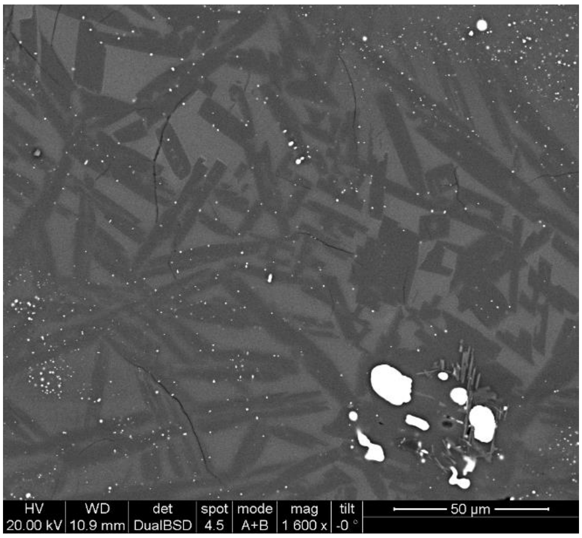
Sample 5 Sample 9

Figure 8.16 - Glassy slag in the interior of the crucibles. Note the quartz crystals (dark grey) in sample 5 and 9.

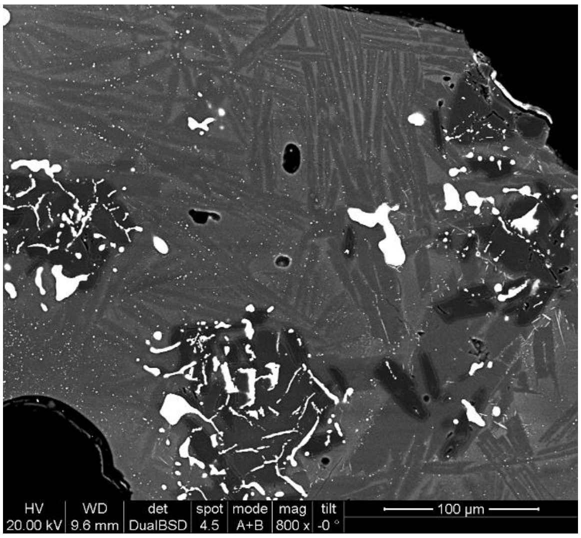
A few samples have features which deserve mention. Samples 14, 15, 18, 22, 23, 29 and 33 have anorthite ($CaAl_2Si_2O_8$) laths which sometimes dominate the entire glassy slag layer. The laths are typically <300µm in length and <50µm in width (Figure 8.17) but do vary considerably in shape and size. Since the polished sample surfaces are essentially two dimensional sections, the orientation of the laths differ causing some of these laths to appear as equiaxed grains in some areas.

Samples 15, 18, 22, 29 and 33 also have a few small concentrations of dark grey rectangular crystals. Individually these crystals are typically <40µm in length and <20µm in width but have a tendency to concentrate in small agglomerations, usually <150µm wide (Figure 8.17). Irregular or globular iron prills also tend to concentrate around these small grain clusters. Spot analyses of the grains reveal that most are corundum (Al_2O_3) but some differ slightly in composition, with up to 18w% MgO and traces of TiO_2, V_2O_5, MnO and FeO.

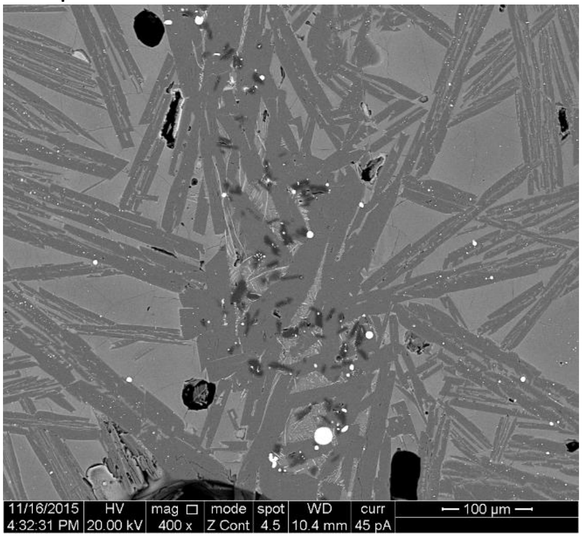
It may be relevant that these exotic minerals were only observed in type 1 and 3 crucibles which are larger than type 2 crucibles. It is possible that their larger size meant that they cooled more slowly allowing more time for the glassy slag to crystallise.



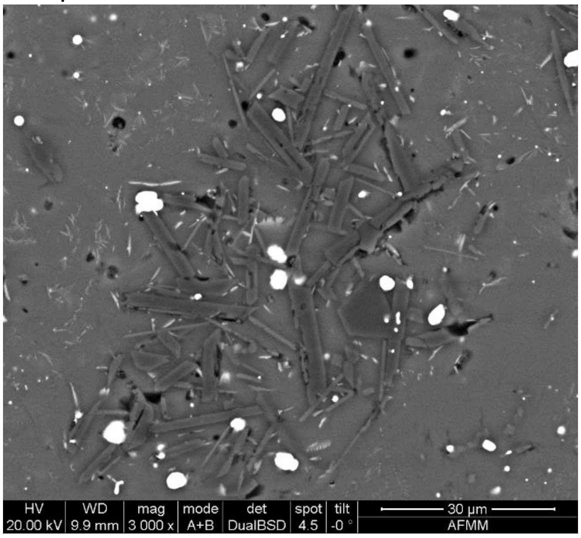
Sample 14



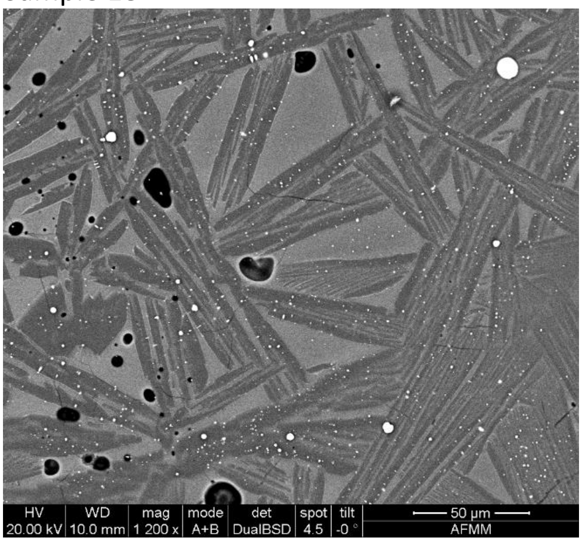
Sample 15



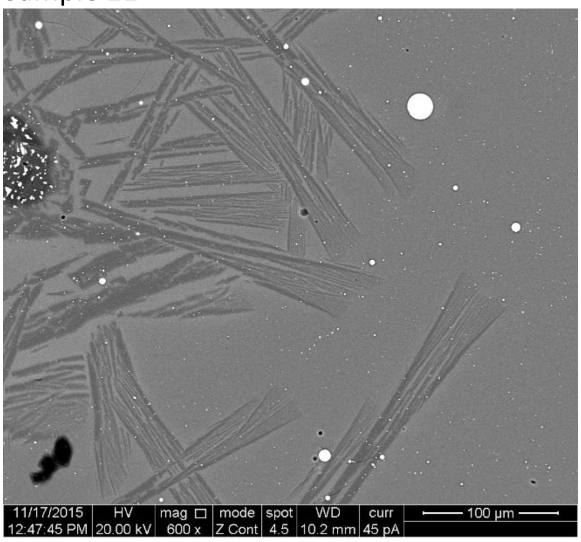
Sample 18



Sample 22



Sample 23



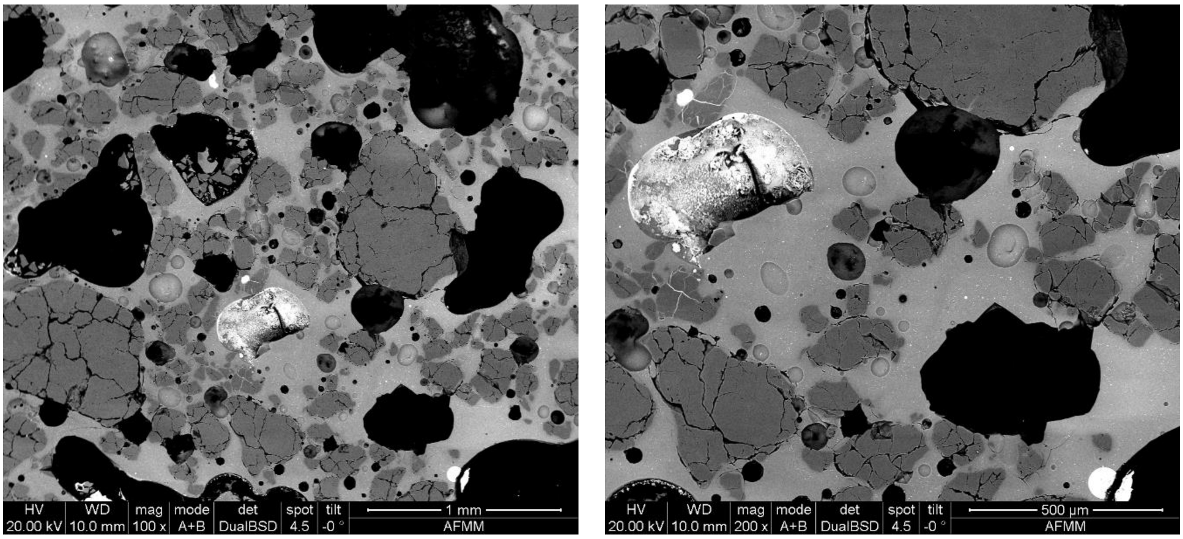
Sample 29

Figure 8.17 - Glassy slag on the interior surface of the crucibles. Note the anorthite laths (mid grey) and corundum grains (dark grey).

8.1.4 Lid

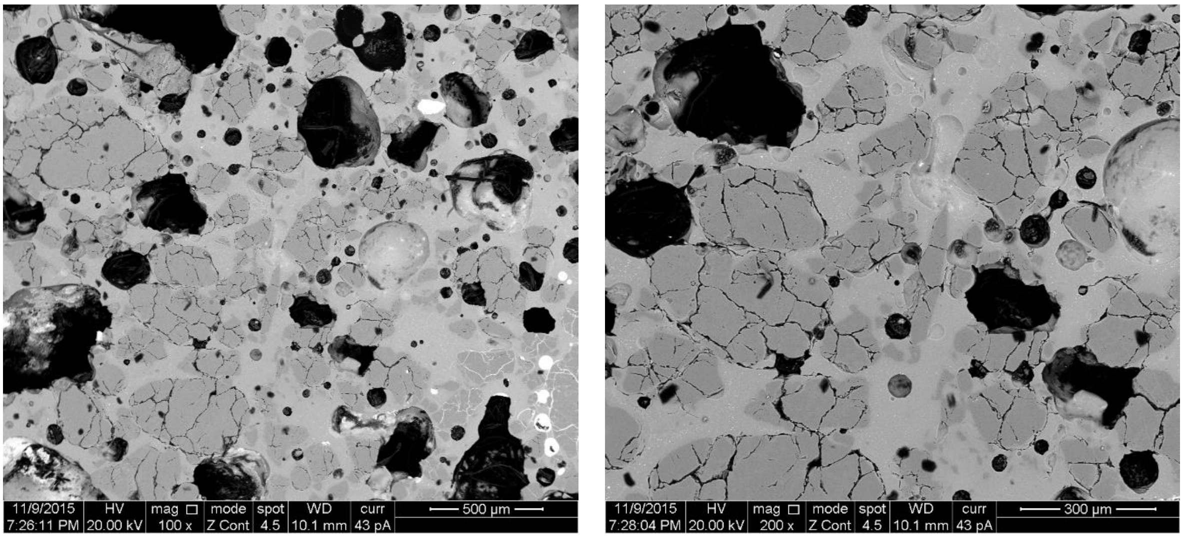
Several lid fragment samples were originally intended for scientific analysis but, as mentioned, because of time and machine availability constraints most had to be removed from the study. Nevertheless, a few of the body fragments sampled were cut to include part of their adhering lid and these were analysed (samples 2, 3, 4, 6, 10, 13 and 23). The morphology of this material has been discussed in chapter 6.2.6.

Lid microstructures were very similar to the coarse vitrified exterior layer of the crucibles (discussed above). In fact, the vitrified parts of the lids were identical in microstructure to the coarse exterior layer. On the whole, the lids appear to be more porous, with the majority having many small spherical voids, <300µm and some larger globular/elongated voids, up to 2mm in size (Figure 8.18). The porosity appears to be greater within the lids, with the exterior surfaces being more vitrified, dominated by the glassy matrix phase.

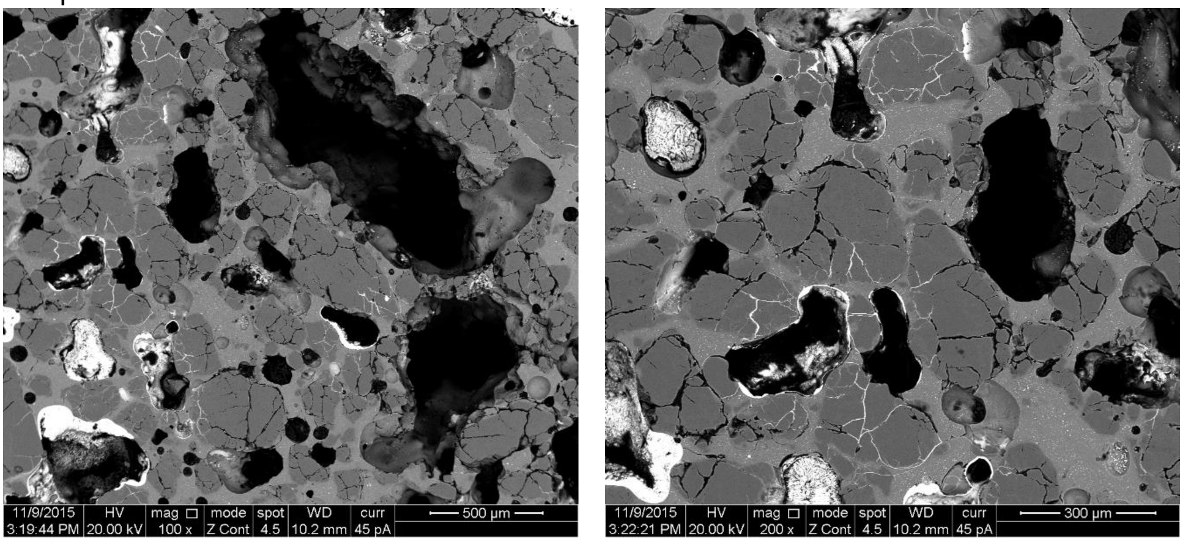


Sample 2

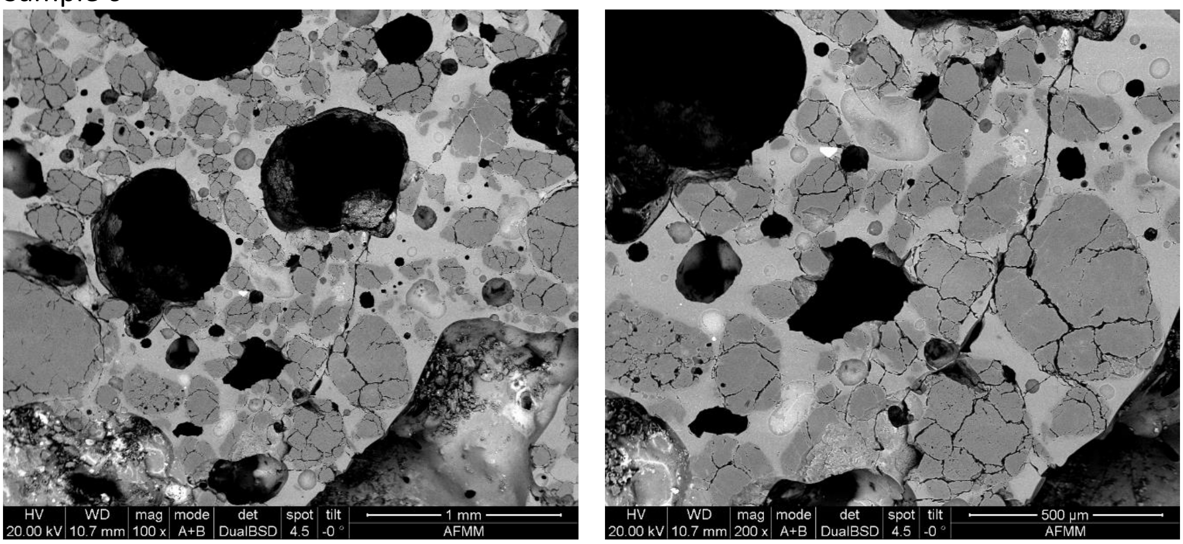
Figure 8.18 – see below



Sample 3



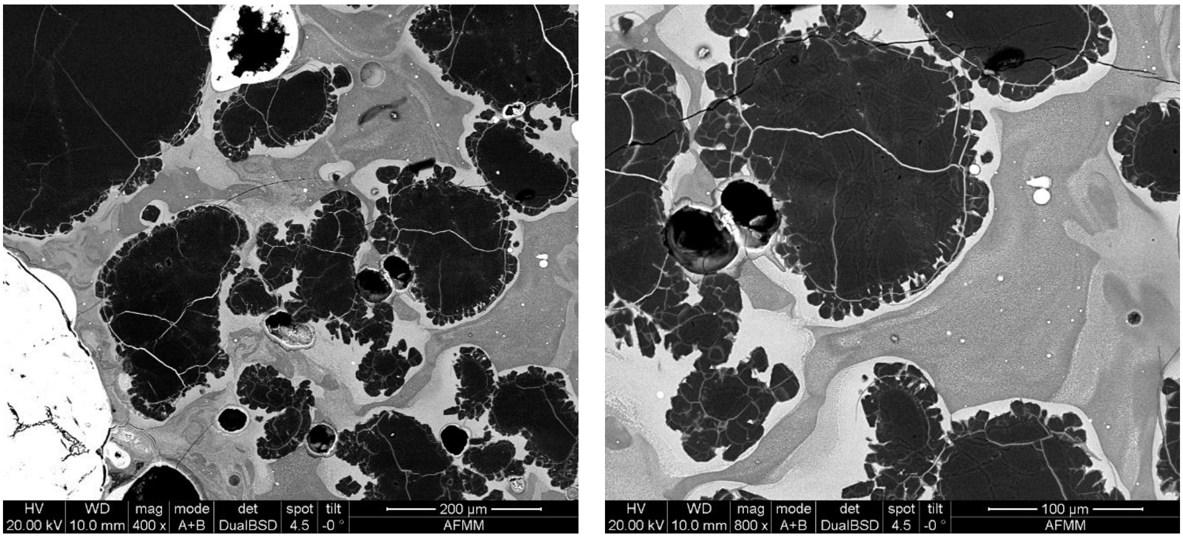
Sample 6



sample 13

Figure 8.18 - Crucible lid fabrics. Note the small spherical voids and larger globular pores (black). Left images 100x and right images 200x of same sample.

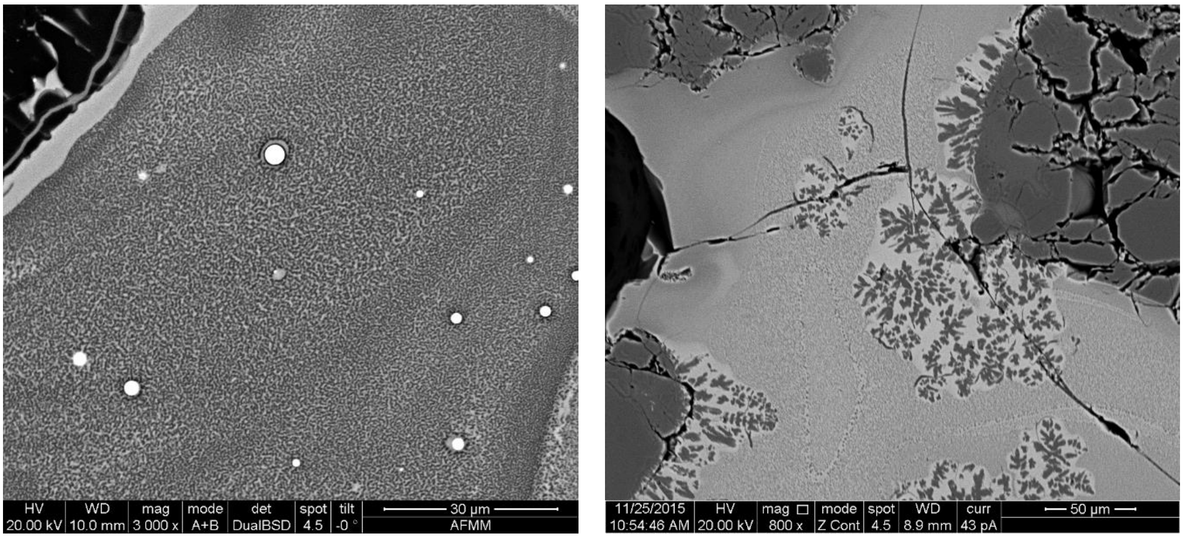
The lid fragments are dominated by large quartz crystals. Most of these are <600µm but can reach up to 2.4mm in size (Figure 8.18). All quartz crystals are cracked and in a few cases appear to have started to break down. A good example of this is found in sample 2. The quartz found close to the interior surface of the lid have started to melt and have recrystallised after cooling, leaving clear reaction rims around larger crystals (Figure 8.19).



Sample 2

Figure 8.19 - Crucible lid in sample 2. Note the recrystallisation on the edges (reaction rim) of some of the quartz crystals (dark grey).

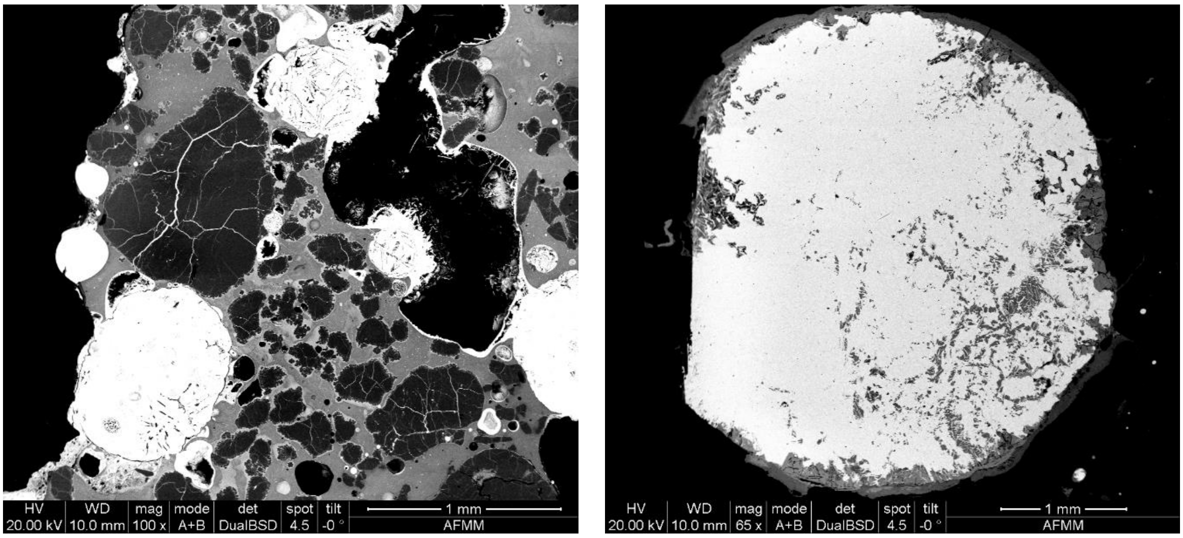
The quartz crystals are embedded within a homogenous glassy matrix devoid of significant microstructural phases. However, in samples 2 and 4 there is some micro-phase separation of the glassy matrix (Figure 8.20). This phenomena was only observed in small localities close to the internal or external surfaces of the lids.



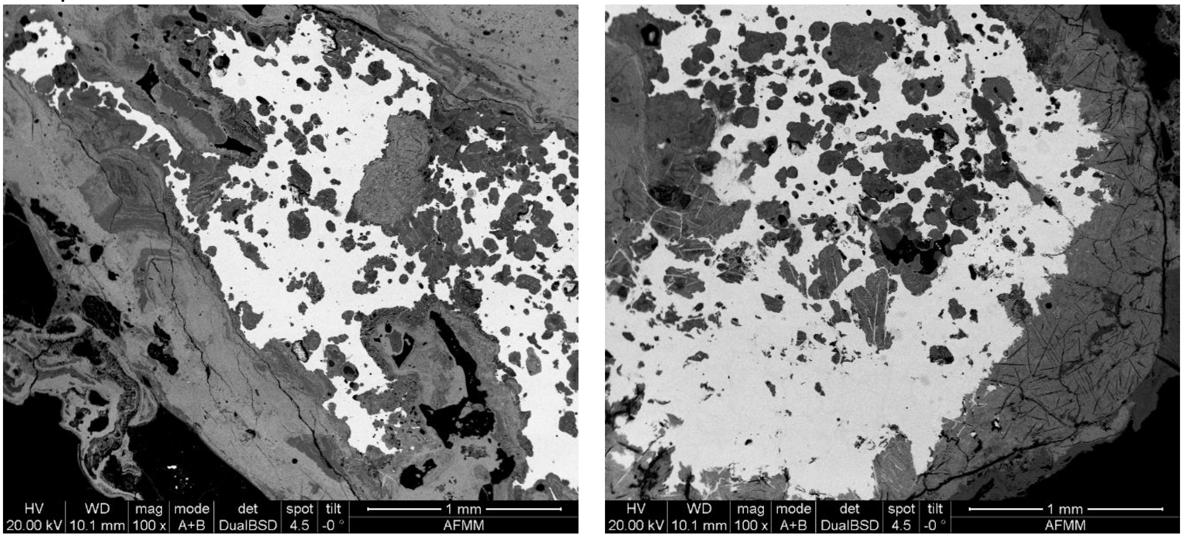
Sample 2 Sample 4

Figure 8.20 - Glassy matrix in some of the crucible lids. Note the micro-phase separation seen in samples 2 and 4.

All examples have very small iron prills randomly precipitated within the matrix. Most of these are <5µm in size but there are a few as large as 130µm. Their occurrence remains sparse but there is some variation between samples. Most notably, samples 3 and 23 display a greater proportion of prills. Sample 2 has several large iron prills close to the interior surface, ranging in size from 150-800µm as well as a larger one, 3.9mm in size (Figure 8.21). Sample 23 also has one very large elongated prill approximately 7mm in length, adhering to the internal surface (Figure 8.21). An interesting feature is that all these larger prills are either adhering or close to the internal surface of the lids, suggesting that they are probably metallic splatters or residues of the crucible charge.



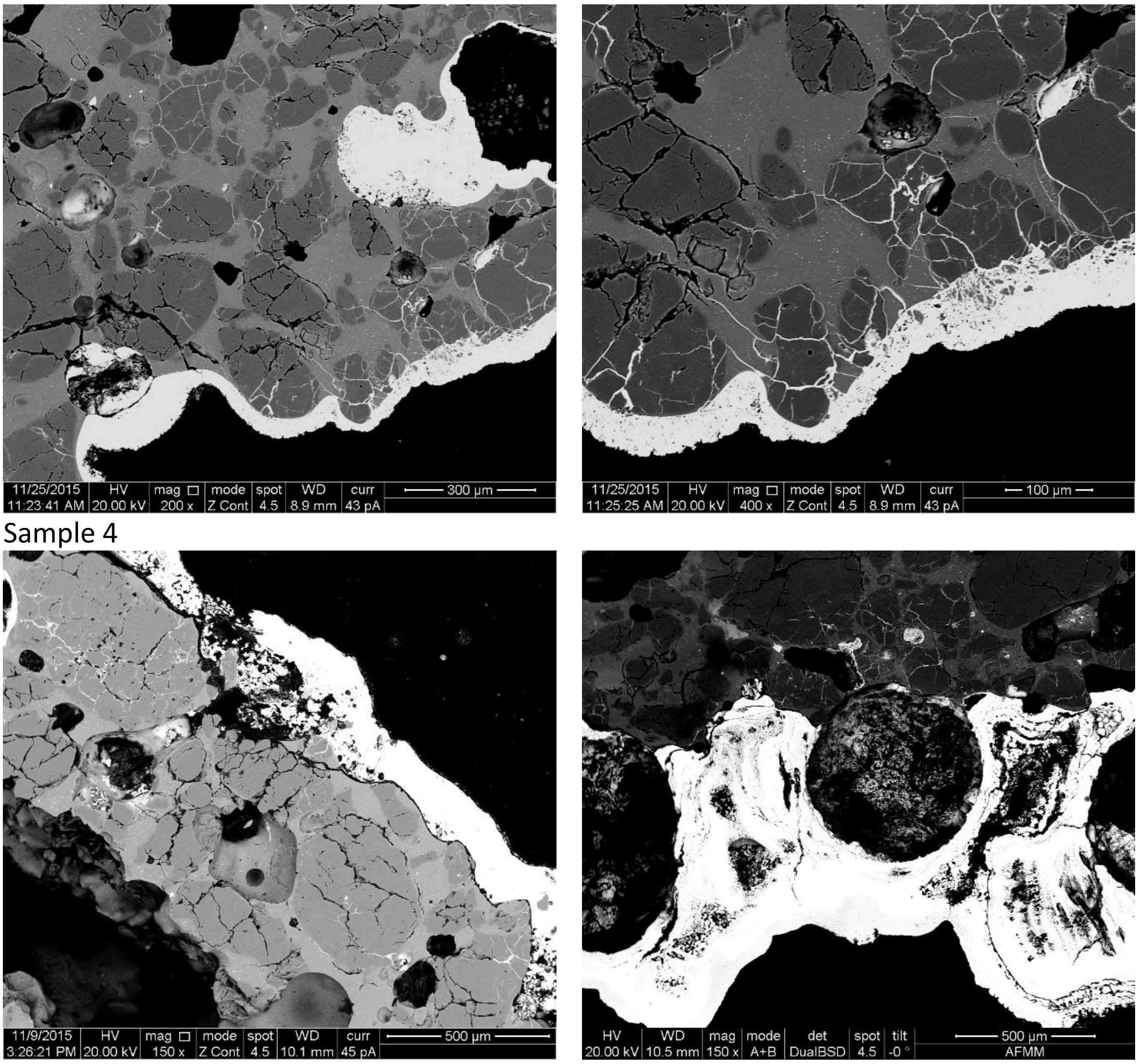
Sample 2



Sample 23

Figure 8.21 - Metallic prills (white) within the crucible lids of sample 2 and 23. Note the more spherical nature of the prills in sample 2 and the large areas of corrosion (light to mid grey) around the large prill in sample 23.

In addition, all examples have a greater amount of iron oxide ‘wash’ on the internal surface (Figure 8.22). In some cases the iron oxide appears to have infiltrated into the lid fabric up to several millimetres, through cracks and voids.



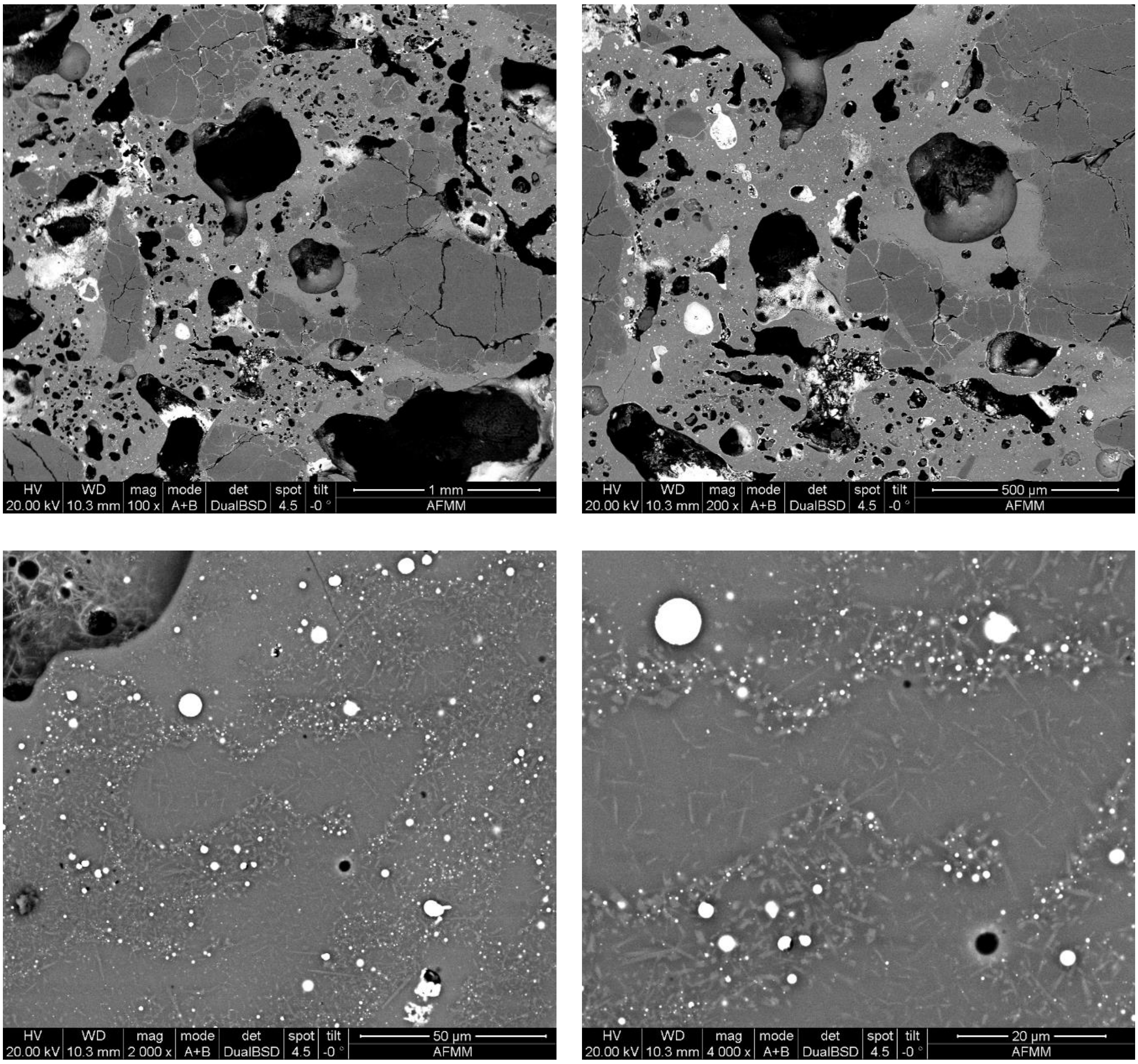
Sample 4

Sample 6 Sample 13

Figure 8.22 - Amorphous iron oxide 'wash' found on the internal surfaces of the crucible lids. Note the infiltration of this iron oxide in some of the cracks.

Sample 23 differs slightly from the other lid fragments as, in addition to large quartz crystals, it also appears to contain an organic component (not identifiable but could be rice husks - Figure 8.23). This leaves a microstructure mixed between features seen in the other lid fragments and features seen in the main crucible body fabric. Organic remains/inclusions are visible between large quartz crystals, randomly distributed across the glassy matrix. In addition, in some areas, numerous very small mullite crystals are present in the glassy matrix, similar to those observed in the main crucible body fabric (Figure 8.23). Since sample 23 is the only example analysed of the type 1 crucibles it is possible that the larger size of the lids caused the fabric to cool more slowly, allowing crystals to form. Lowe (1989a, 737;

1989b, 246) describes the presence of broken refractory vessel fragments in the lid fabrics of the crucibles from Konasamudram. This was not observed in sample 23 but this may be because only the more vitrified parts of the lid (not more than 20mm from the lid exterior surface) where sampled and analysed. Since sample 23 is from Konasamudram, it is possible that some of the microstructural features described above came from recycled vessel fragments used as grog. This will need clarification in future studies with the analysis of a greater number of type 1 crucible lid samples.

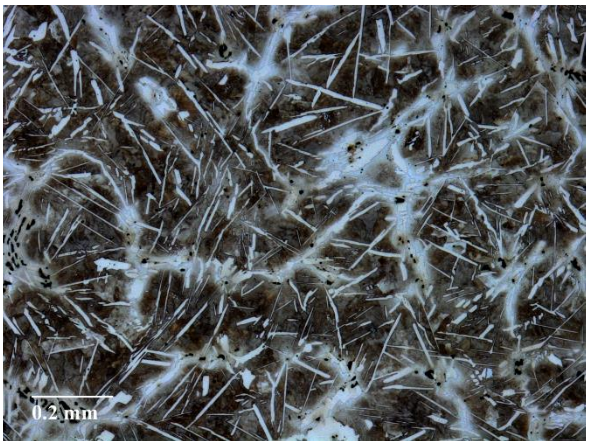


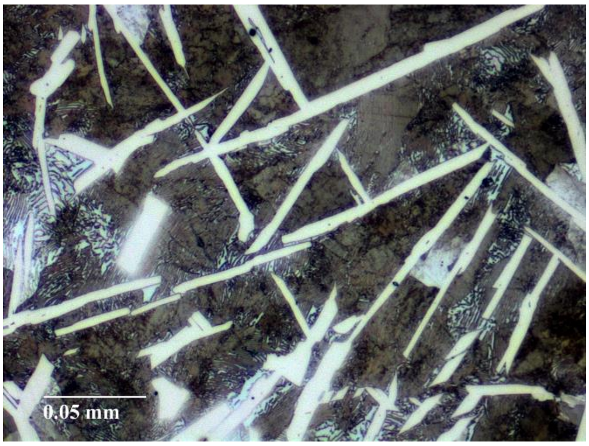
Sample 23

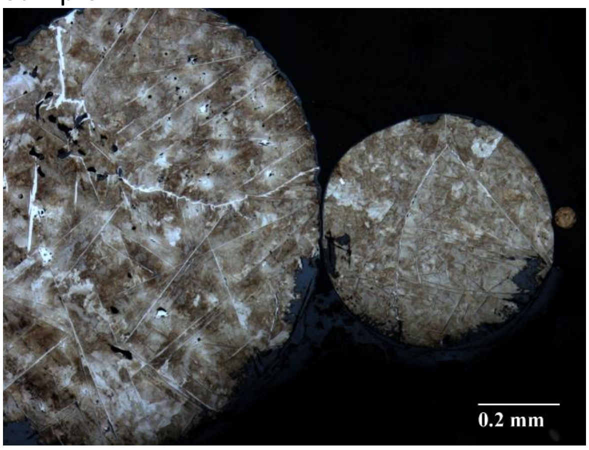
Figure 8.23 - Crucible lid from sample 23. Note the organic component which has left irregular voids between the quartz crystals (top images) and the presence of mullite crystals in some areas of the glassy matrix (bottom images).

8.1.5 Metallic Prills

The large metallic iron prills identified on the internal lid surfaces of samples 2 and 23 were etched and observed by optical microscopy. The prills in sample 2 are all spherical in shape and solid in nature with few to no internal voids. These prills included several up to 800µm in size and one larger prill 3.9mm (Figure 8.24). All proved to have homogenous hyper-eutectoid steel microstructures. No exotic features were noticed and the microstructures did not differ significantly from the centre to the edges of the prills, hence homogenous in nature. They were dominated by elongated cementite needles sometimes surrounded by a thin ferrite layer within a pearlitic matrix (Figure 8.24). The pearlite was both lamellar and degenerate in some areas, with the former 'ghost' austenite grain boundaries visible. These prills are well preserved with very little corrosion observed on their exposed surfaces.



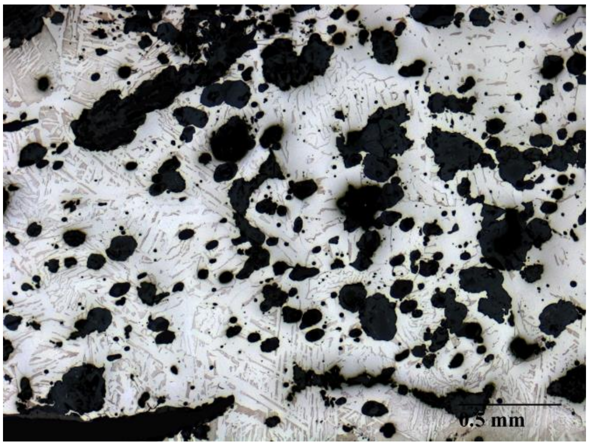


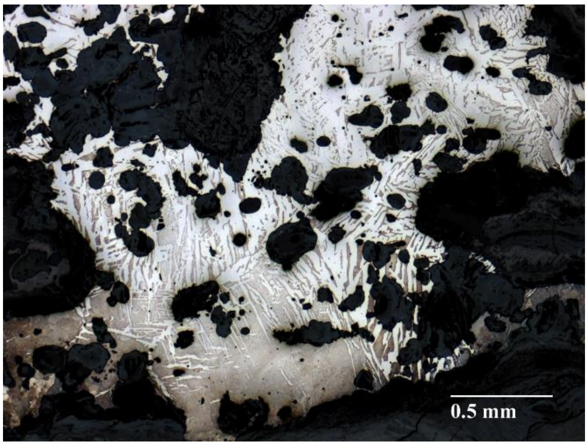
Sample 2


Sample 2

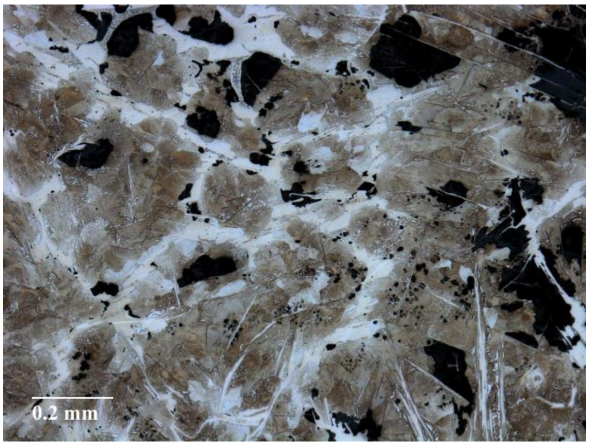
Figure 8.24 - Spherical hyper-eutectoid steel prills in sample 2. Note the cementite needles (beige) surrounded by thin ferrite (white) in a pearlitic matrix (darker background).

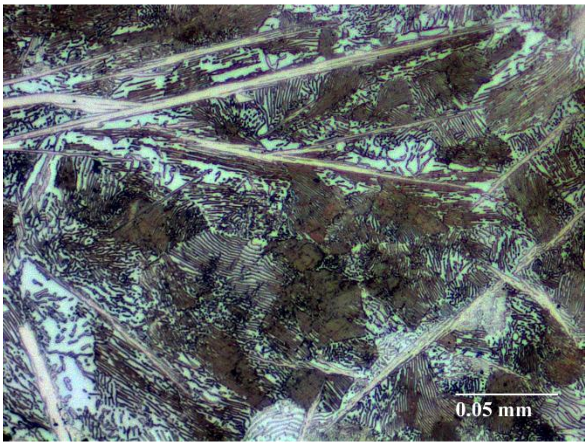
The large elongated prill, approximately 7mm in length, in sample 23 differed slightly and was on the whole less homogenous. The prill was not as consolidated as those in sample 2, being porous in nature. Many small spherical and irregular voids were present, randomly distributed throughout the prill (Figure 8.25). The microstructure observed showed a slight difference in microstructure from the centre of the prill to the edges. The prill was hyper-eutectoid but the centre portions appeared to have a more compact mass of Widmannstätten cementite and ferrite needles with small areas of lamellar pearlite separating the needles (Figure 8.25). On the edges the lamellar pearlite matrix dominated the microstructure, with sparse cementite needles on former austenite grain boundaries (Figure 8.25). The cementite needles were sometimes surrounded with a thin layer of ferrite. The prill appears to be corroded on the edges, with a layer of corrosion surrounding it up to several millimetres thick. However, it is possible in some of the corroded parts to observe relic structures preserved, revealing the areas to have been of a high carbon content dominated by cementite and pearlite (Figure 8.25), very similar to the remaining edges described above. The original size of the prill is likely to have been as large as 11mm in length.



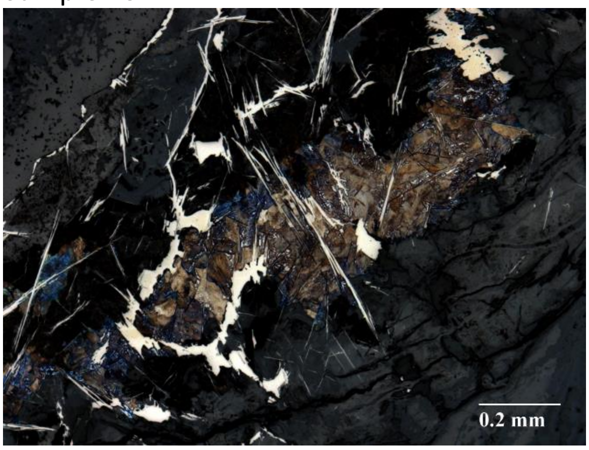


B+W





Sample 23



Sample 23

Figure 8.25 - Large elongated hyper-eutectoid steel prill in sample 23.The top images are black and white showing the centre of the prill dominated by dense Widmannstätten cementite and ferrite. The images in the centre show the higher carbon content found on the edge of the prill with cementite needles (beige) surrounded by thin ferrite (white) in a pearlitic matrix (darker background). The bottom image shows part of the corroded rim surrounding the prill with evident remains of cementite and pearlite.

8.2 Compositional Analyses

The following section will deal with the elemental analysis results for each crucible material component. All samples were analysed as set out in chapter 4.3.4. The P_2O_5 and SO_3 contents could not be confirmed through the analysis of standards (chapter 4.3.4), hence the reliability of the data is uncertain and given values below 0.2wt% should be taken with caution.

8.2.1 Exterior Coarse Layer

The average chemical compositions of the exterior coarse layer of each sample are given in table 8.2 below. All the exterior layer compositions are reasonably similar, with MgO contents between 0.6 and 2.2wt%; Na_2O between 0.2 and 1.3wt%; TiO_2 between 0.3 and 1.0wt%; K_2O between 0.9 and 6.1wt%; FeO between 1.6 and 6.1wt% (except sample 2 with 14.1wt%). Most variation is seen in the Al_2O_3 (4.8 to 17.0wt%), SiO_2 (60.4 to 84.5wt%) and CaO (1.8 to 12.0wt%) contents. This difference in composition is not unusual in ceramics and is indicative of variations in manufacture, the raw materials used (clays, organic/mineral content and quartz) or at least their proportional occurrence. Since the exterior layer was in direct contact with furnace environment, the burning fuel (charcoal) undoubtedly contributed to the clay composition, perhaps explaining the small variations in P_2O_5, K_2O and CaO content. FeO and TiO_2 are present in most clays and their respective 3-5wt% and 1.0wt% contents in most samples is common.

Table 8.2 - Average exterior coarse layer chemical compositions in all crucible samples (normalised SEM-EDS data).

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
1	0.5	1.1	6.8	84.3	BDL	BDL	1.5	1.8	0.5	BDL	3.5
2	0.4	0.7	4.8	76.5	BDL	BDL	0.9	1.9	0.4	0.1	14.1
3	0.6	1.0	5.7	84.5	BDL	BDL	1.0	2.7	1.0	0.1	3.6
4	0.5	0.9	5.1	82.6	BDL	0.1	0.8	6.2	0.4	BDL	3.4
5	0.5	0.9	5.9	82.7	BDL	BDL	1.8	4.4	0.6	BDL	3.0
6	0.7	0.6	8.7	80.1	BDL	BDL	5.1	2.8	0.3	BDL	1.6
7	0.4	1.2	8.2	76.2	BDL	0.1	3.1	6.6	0.5	BDL	3.7
9	0.3	1.2	9.4	79.7	BDL	0.1	2.7	2.6	0.4	BDL	3.5
10	0.2	1.5	8.2	78.2	0.1	BDL	2.1	6.2	0.5	BDL	3.0
12	0.4	1.3	7.5	74.3	0.1	BDL	2.6	7.4	0.4	BDL	5.9
13	0.4	1.1	6.1	80.7	0.2	BDL	1.6	5.9	0.5	BDL	3.4
14	0.7	1.7	16.4	60.4	0.1	BDL	6.1	10.4	0.5	BDL	3.8
15	0.5	0.7	10.0	79.8	BDL	BDL	3.8	2.6	0.4	BDL	2.2
16	0.6	1.0	14.1	72.5	0.2	BDL	5.1	3.0	0.4	BDL	3.1
17	0.7	1.6	14.1	67.3	0.4	BDL	5.6	6.3	0.4	BDL	3.6
18	0.8	1.7	14.6	69.5	0.2	0.1	3.8	4.4	0.5	BDL	4.3
20	0.6	1.3	17.0	65.8	0.3	BDL	3.9	6.1	0.6	BDL	4.4
22	0.6	1.3	16.8	64.9	0.3	BDL	3.6	5.8	0.6	BDL	6.1
23	0.5	1.2	13.7	71.6	BDL	BDL	3.5	5.6	0.5	BDL	3.4
24	0.5	2.2	15.5	63.4	0.4	BDL	4.4	9.6	0.5	BDL	3.4
26	0.5	1.7	14.3	67.8	0.4	BDL	4.2	6.0	0.5	BDL	4.5
27	1.3	1.5	11.3	72.8	0.5	BDL	4.8	4.3	0.3	BDL	3.1
29	BDL	1.0	7.7	73.1	BDL	0.1	1.7	12.0	0.6	BDL	3.8
31	0.2	0.6	8.7	75.8	BDL	BDL	2.0	7.8	0.6	0.2	4.0
33	0.8	0.7	15.6	72.8	BDL	BDL	4.4	2.0	0.5	0.1	3.1

8.2.2 Crucible Main Body

All the main body fabrics were also analysed and their average chemical compositions are given in table 8.3. All samples have Na_2O contents between 0.2 and 0.9wt%; MgO between 0.7 and 2.8wt%; Al_2O_3 between 18.5 and 27.4wt%; SiO_2 between 53.5 and 69.0wt%; P_2O_5 all under 0.8wt%; K_2O between 1.8 and 3.8wt%; CaO between 0.8 and 2.5wt% (except sample 23 with 5.9wt%); TiO_2 between 0.7 and 1.5wt% and FeO between 5.5 and 16.3wt%. Once again the small variations in chemical composition probably reflect differences in the recipes used to make the crucible body fabric, the choice of raw materials used or the proportions of each. Most variation is seen in the Al_2O_3 and SiO_2 contents, which may reflect the amount of quartz used in the mixture or choice of different clays. Another element which varies is the FeO content, which may be due to the amount of iron oxide present in different clays used or even the infiltration of Fe from the crucible charge. Nevertheless, it is evident that out of all the crucible material layers analysed the main body is by far the most consistent. This suggests that very similar recipes were used in all crucible steel sites or that they were made at one location or by one artisan.

Table 8.3 - Average main body fabric chemical compositions in all crucible samples (normalised SEM-EDS data).

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
1	0.7	2.5	22.0	60.5	0.5	BDL	1.9	1.8	0.8	BDL	9.4
2	0.8	2.7	25.0	56.2	0.2	0.2	2.1	2.2	1.0	0.2	9.4
3	0.8	2.2	23.3	57.8	0.2	BDL	1.9	2.3	1.5	BDL	10.0
4	0.7	1.6	23.6	57.9	BDL	0.1	1.8	1.9	1.0	BDL	11.2
5	0.7	1.8	23.8	57.0	0.3	0.1	2.0	1.5	1.0	BDL	11.8
6	0.3	1.9	23.5	53.5	0.2	0.2	2.6	0.8	0.9	0.1	16.3
7	0.6	1.5	27.4	54.8	0.2	BDL	2.2	1.5	1.2	0.2	10.5
9	0.4	2.4	24.2	54.3	0.3	0.2	2.0	1.6	1.1	BDL	13.5
10	0.3	1.8	20.2	61.5	0.4	BDL	2.7	1.4	1.3	0.2	10.2
12	0.3	2.8	21.5	56.6	0.3	0.1	2.1	1.4	1.1	0.1	13.9
13	0.3	1.4	23.5	55.9	0.1	BDL	2.3	1.5	1.1	0.2	13.5
14	0.6	1.4	22.4	60.2	0.3	0.1	3.5	1.5	0.9	0.1	9.2
15	0.9	1.1	20.8	63.6	0.1	0.1	3.8	1.3	1.1	BDL	7.2
16	0.5	1.7	22.9	60.5	0.4	0.2	3.2	1.4	0.9	0.2	8.2
17	0.6	1.2	21.5	63.0	0.3	0.1	3.5	1.2	1.0	BDL	7.4
18	0.8	1.2	19.1	60.4	0.8	BDL	2.4	2.2	0.7	0.1	12.3
19	0.7	1.4	20.6	61.5	0.3	0.2	2.5	2.5	0.8	BDL	9.5
20	0.7	1.3	24.8	58.9	0.2	0.2	2.8	1.5	0.9	0.1	8.7
22	0.8	1.7	19.3	64.6	0.3	0.2	3.6	1.4	0.7	0.1	7.5
23	0.6	2.2	20.6	59.8	0.2	BDL	3.0	5.9	0.8	0.2	6.9
24	0.7	1.2	22.3	61.2	0.6	BDL	3.1	1.7	1.4	BDL	7.8
26	0.5	1.6	23.5	58.9	0.5	BDL	2.5	2.0	0.9	BDL	9.7
27	0.7	1.7	18.5	64.2	0.5	BDL	2.8	2.0	1.0	BDL	8.8
29	0.2	0.7	20.8	65.5	0.1	0.2	2.8	1.0	1.2	0.1	7.5
31	0.2	0.9	19.9	69.0	BDL	BDL	2.4	0.9	1.1	BDL	5.5
33	0.5	1.4	19.9	62.7	0.3	0.1	3.0	1.6	1.0	BDL	9.2

8.2.3 Internal Glassy Slag

All the internal crucible glassy slag layers were analysed and the results are presented in table 8.4. It is important to mention that the chemical compositions presented for samples 15, 22 and 33 are likely to be the vitrified internal wall (main body fabric) as the areas analysed were very thin. The glassy slag compositions show a large degree of variation across all samples. They vary in Na_2O contents between 0.2 and 1.0wt%; MgO between 1.9 and 7.4wt%; Al_2O_3 between 11.2 and 32.7wt%; SiO_2 between 46.0 and 67.2wt%; K_2O

between 1.5 and 4.8wt%; CaO between 2.6 and 18.6wt%; TiO_2 between 0.6 and 7.7wt%; MnO between 0.1 and 2.7wt% and FeO between 1.2 and 26.1wt%. This large degree of variation could have resulted and be indicative of different crucible charges reacting at high temperatures. However, variation may also have occurred due to the differing contributions of all the components which the glassy slag likely constitutes. These most certainly include the crucible main body fabric, the lid fabric and the crucible charge. The compositional proportions to which these may have contributed to the glassy slag material increase the probability of varying compositions.

Table 8.4 - Average internal glassy slag chemical compositions in each crucible sample (normalised SEM-EDS data).

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
1	0.9	2.2	11.2	49.6	0.1	0.1	1.6	7.1	0.6	0.4	26.1
3	1.0	3.3	13.4	67.2	BDL	BDL	1.5	9.4	1.3	0.4	2.4
5	0.7	2.7	13.7	64.9	BDL	BDL	1.7	11.5	3.4	0.2	1.2
6	0.4	4.3	16.6	48.6	BDL	0.1	2.8	17.8	7.7	0.1	1.7
7	0.4	7.4	15.1	61.1	BDL	BDL	2.1	11.4	0.7	0.1	1.8
9	0.7	3.0	15.6	63.2	BDL	BDL	4.8	6.4	3.6	0.2	2.6
10	0.5	2.7	18.4	60.7	BDL	0.1	3.2	7.4	4.6	0.1	2.4
12	0.4	6.5	14.8	62.9	BDL	BDL	2.9	8.6	1.1	0.4	2.6
14	0.5	3.0	26.0	48.0	BDL	BDL	2.2	15.4	2.6	0.4	1.8
15	0.8	2.3	18.8	56.4	0.1	0.1	2.7	13.2	3.4	0.7	1.5
16	0.6	2.6	20.2	59.5	BDL	BDL	3.7	8.5	2.9	0.3	1.7
17	0.7	2.2	26.6	50.4	BDL	0.1	4.0	7.3	3.0	1.3	4.4
18	0.5	3.2	25.8	46.0	BDL	BDL	2.4	15.8	3.2	0.8	2.4
20	0.6	3.1	32.7	46.1	BDL	BDL	1.7	10.9	2.9	0.4	1.8
22	0.3	2.2	20.0	53.0	0.7	BDL	4.3	11.4	0.8	0.1	7.3
23	0.4	2.8	24.5	48.2	BDL	BDL	2.5	15.8	3.7	0.6	1.7
24	0.4	3.2	25.6	47.5	BDL	0.1	1.9	16.8	2.8	0.5	1.3
26	0.5	2.7	11.8	66.2	BDL	BDL	4.1	9.7	0.6	0.4	3.9
29	0.2	2.7	21.3	50.3	BDL	BDL	2.3	18.6	1.2	1.7	1.7
31	0.2	2.9	19.6	50.7	BDL	BDL	3.9	16.6	1.0	2.7	2.5
33	0.8	1.9	26.4	58.0	BDL	BDL	4.5	2.6	1.0	0.1	4.6

8.2.4 Lid

The results of the lid fragments analysed are given below in table 8.5. On the whole, the lid chemical compositions of most samples are similar to one another. They range in Na_2O contents between 0.3 and 0.6wt%; MgO between 0.6 and 1.2wt%; Al_2O_3 between 5.2 and 12.7wt%; SiO_2 between 73.8 and 87.9wt%; K_2O between 0.7 and 3.0wt%; CaO between 0.5

and 3.6wt%; TiO_2 between 0.3 and 0.5wt% and FeO between 3.4 and 9.9wt%. Similar to the coarse exterior layer, the most variation in composition is seen in the Al_2O_3 and SiO_2 content, with smaller variations in K_2O, CaO and FeO, signifying potential use of different clays or mixtures of raw materials.

Table 8.5 - Average lid chemical compositions of in all samples (normalised SEM-EDS data).

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
2	0.6	1.2	6.9	78.3	0.1	BDL	1.0	1.4	0.5	0.1	9.9
3	0.5	0.7	5.2	87.9	BDL	BDL	0.7	1.4	0.4	BDL	3.4
4	0.6	0.7	5.5	85.3	BDL	BDL	0.8	2.2	0.5	0.1	4.3
6	0.3	0.6	5.4	84.4	BDL	0.2	1.3	0.8	0.3	BDL	6.6
10	0.3	0.9	9.2	82.4	0.1	BDL	1.7	0.5	0.4	BDL	4.7
13	0.4	0.8	6.7	82.9	0.1	BDL	1.7	3.6	0.3	BDL	3.4
23	0.5	0.9	12.7	73.8	BDL	BDL	3.0	1.7	0.4	BDL	7.0

8.2.5 Metallic Prills

Several spot elemental analyses were taken of the prills in samples 2 and 23 discussed above. Their compositions proved to be almost identical. They were mostly pure iron with very small contents of SiO_2 (<0.3wt%) and P_2O_5 (<0.2wt%). Some of the larger prills (>150µm) found in the internal glassy slags were also analysed in several samples, proving to be very similar, with SiO_2 and P_2O_5 contents <0.3wt%. The only difference is that many had very small Al_2O_3 and V_2O_5 contents, <0.2wt%. The most interesting trend is that prills from site PM60 (samples 14, 15 and 16) appear to contain greater amounts of V_2O_5 up to 0.7wt%. The fully quantitative results will not be provided and discussed any further as the reliability of the data was not checked due to the lack of suitable standards. Nevertheless, future studies on the metallic prills in crucibles will be informative.

8.3 Discussion

This section will discuss the microstructural observations and elemental analyses of the crucible ceramic and slag layers described. The results were probed for patterns and trends which may point to differences in manufacture and use at site and intra-site level. In addition, patterns were investigated which may identify differences between the three morphological crucible types (chapter 6.2.6). The results are also compared with published data of other crucible productions sites in Central and South Asia.

8.3.1 Composition Comparisons and Variation in Microstructure

The majority of the microstructural observations show no apparent differences between sites and the three crucible types. The composition and variance between the main crucible ceramic layers will be discussed here.

The external coarse layer is dominated by quartz crystals in a generally homogenous glassy matrix. On the whole the external layers of crucible type 2 appear to have denser concentrations of quartz crystals but no other identifiable variations are apparent. There is also some small variations in porosity, but this appears to be random, showing no discernible correlation to crucible type or site. There has been some debate amongst academics as to the nature of this vitrified quartz-rich layer with suggestions ranging from a clay, to the crucibles having been rolled in crushed quartz to protect the crucible from the high temperatures reached in the firing process (Balasubramaniam *et al* 2007; Lowe 1989a, 1989b; Srinivasan 2007, 680). However, no previous studies have scientifically analysed the external layer. The morphological observations of the crucibles and the microstructural evidence provided in this study indicates that this layer is in fact a coarse-quartz rich clay. It appears to have been deliberately spread on the external surface of all the crucibles collected and consequently became fully vitrified in the high operating temperatures, resulting in the loss of any identifiable microstructure. Due to the high quartz content it is not unreasonable to suggest that sand or crushed quartz or quartzite was intentionally added to the clay mixture in an attempt to improve its refractory properties. The elemental analyses show typical clay compositions predominantly constituted of SiO_2 and Al_2O_3, with smaller components of MgO, K_2O, CaO and FeO.

The main body fabrics of all crucible samples are also very similar to one another, showing no major correlation between sites or crucible type. All examples are dominated by elongated voids created by the remains of rice husks, in a predominantly homogenous glassy matrix. Sparse silica grains are present within the microstructure and abundant small iron prills often dominate the glassy matrix. At high magnifications very small mullite crystals can be seen concentrating within the glassy phase. This microstructure is consistent throughout all the samples analysed, with variation only noticeable in levels of porosity which do not appear to be associated with particular sites or crucible type. The exception is the small difference in quartz content with crucibles of type 1 and 3 appearing to contain a little more than type 2. This could result from different clays or recipes used in their construction, but the variations in microstructure are slight, suggesting very consistent production methods across all sites or more centralised crucible manufacture. Microstructurally, the main body fabric differs considerably from the coarse exterior layer, with significantly less quartz crystals. This is reflected in the chemical compositions, resulting in lower SiO_2 and higher Al_2O_5 content. There is also a noticeable increase in FeO and decrease in CaO suggesting that a different type of clay was used.

Another interesting point is that the unused crucible fragment analysed (sample 19) has an identical chemical composition to the all the other main body fabrics of type 1. This suggests that the fabrics changed very little despite having been subjected to such high firing temperatures. However, it is important to point out that carbon was not probed for and the used crucibles likely had greater carbon contents (perhaps supported by the fact that they all have very black fabrics) than the unused sample 19 (which was orangey in colour).

Microstructurally, the internal glassy slag layers show the most variation. For the most part, they are homogenous and entirely glassy with no evident microstructure except an abundance of very small iron prills randomly precipitated within the phase. However, several samples (14, 15, 18, 22, 23, 29 and 33) have well formed anorthite laths and very small grains with compositions close to corundum, but with varying contents of MgO and traces of TiO_2, V_2O_5, MnO and FeO. Interestingly, these are only present in crucibles of type 1 and 3. Due to the relative similarity of glassy slag chemical compositions across all crucible types, this difference could be attributable to the larger size of type 1 and 3 crucibles. It is possible that their larger size (thicker walls) resulted in the slower cooling of the internal content, allowing more time for crystal growth. The chemical composition of the glass is mostly SiO_2, Al_2O_3 and CaO, with smaller quantities of MgO, K_2O, TiO_2, MnO and FeO. It is interesting to point out that there is considerably more TiO_2, CaO and MnO in the glassy slags than the ceramic components of the crucibles, suggesting that the charge may have contributed more to the glass composition. Although TiO_2 and MnO are typical components of iron ore and could have been introduced to the crucible charge in the form of slag trapped in the metal, the surprisingly high CaO content suggests that a flux was introduced to the process, such as limestone which is commonly found on metallurgical sites in Telangana (chapter 6.2.9).

The lid microstructures are interesting. The majority are very similar to one another, primarily composed of dominant quartz crystals in a glassy matrix often containing randomly precipitated small iron prills. Some minor variation in porosity is apparent but does not correlate between sites or crucible type. However, it is evident that one sample differs from the others. Sample 23 has an organic component which is likely to be rice husks. Although only one crucible lid of type 1 was analysed, it suggests that there may be a difference in composition between the crucibles lid fabrics of different types. Lowe (1989a; 1989b) observed re-used vessel fragments within the lid fabrics of crucibles from Konasamudram (the same site on which sample 23 was collected) suggesting that the organic components may have come from these. However, these grog inclusions were not described in detail by Lowe and were not observed in this study, negating further comments until future work assesses the nature of these inclusions. Nevertheless, it is probable that different ingredients were used in the lid fabrics of type 1 crucibles. As a whole, the lids have a very similar microstructure and composition to the coarse exterior layers, with SiO_2 and Al_2O_5 being dominant and comparable MgO, K_2O, CaO, TiO_2 and FeO contents.

In fact, when comparing the composition of any sample with that of its exterior layer, they are almost identical (Table 8.6). This strongly suggests that the lid and exterior layer are made of the same quartz-rich clay and the exterior coating was applied when the crucibles were plugged with their lids. Extra material was smeared onto the crucible sides, sealing the junction between body and lid as discussed in chapter 6.2.6. This is supported by the seamless transition between the exterior layers and lids observed macroscopically and microscopically. The main variations are in SiO_2 and CaO content, with lids consistently having 2-5wt% more SiO_2 and 1-5wt% less CaO than the exterior layers. The reason for this difference is uncertain but it was noticed that on most samples there were less quartz crystals on the exterior surface which may account for the reduction in SiO_2. The proportional increase in glassy matrix could also account for the extra CaO seen in the external layers, but if this was the case then one might expect to also see an increased Al_2O_3 content, since both elements are dominant (after SiO_2) in the glassy matrix phase. A possibility may be that the external surfaces of the crucibles were coated with crushed limestone as an additional protection from the high temperatures. Limestone ($CaCO_3$), having a relatively low melting point (825°C), would most certainly have melted forming a surface glaze. It may account for the greenish-blue vitrified glazing seen on most of the crucible's external surfaces (chapter 6.2.6). Although this remains a hypothesis, the fact that limestone was regularly found on some of these production sites may lend credence. Another possibility of course, accounting for higher CaO contents could be the contribution of fuel (wood/charcoal) ash to the exposed exterior of the crucible from the furnace fuel and environment.

Table 8.6 – Comparison in composition between lid and exterior layers in individual samples.

Sample		Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
2	lid	0.6	1.2	6.9	78.3	0.1	BDL	1.0	1.4	0.5	0.1	9.9
	ext. l	0.4	0.7	4.8	76.5	BDL	BDL	0.9	1.9	0.4	0.1	14.1
3	lid	0.5	0.7	5.2	87.9	BDL	BDL	0.7	1.4	0.4	BDL	3.4
	ext. l	0.6	1.0	5.7	84.5	BDL	BDL	1.0	2.7	1.0	0.1	3.6
4	lid	0.6	0.7	5.5	85.3	BDL	BDL	0.8	2.2	0.5	0.1	4.3
	ext. l	0.5	0.9	5.1	82.6	BDL	0.1	0.8	6.2	0.4	BDL	3.4
6	lid	0.3	0.6	5.4	84.4	BDL	0.2	1.3	0.8	0.3	BDL	6.6
	ext. l	0.7	0.6	8.7	80.1	BDL	BDL	5.1	2.8	0.3	BDL	1.6
10	lid	0.3	0.9	9.2	82.4	0.1	BDL	1.7	0.5	0.4	BDL	4.7
	ext. l	0.2	1.5	8.2	78.2	0.1	BDL	2.1	6.2	0.5	BDL	3.0
13	lid	0.4	0.8	6.7	82.9	0.1	BDL	1.7	3.6	0.3	BDL	3.4
	ext. l	0.4	1.1	6.1	80.7	0.2	BDL	1.6	5.9	0.5	BDL	3.4
23	lid	0.5	0.9	12.7	73.8	BDL	BDL	3.0	1.7	0.4	BDL	7.0
	ext. l	0.5	1.2	13.7	71.6	BDL	BDL	3.5	5.6	0.5	BDL	3.4

8.3.2 Compositional Analysis by Crucible Type

The microstructures have shown that the crucible material layers are made from different ingredients, with a coarse quartz-rich clay coating on the exterior and a fine rice husk tempered clay for the main body. However, the microstructural observations did not reveal any significant variations in ceramic manufacture from sample to sample (except perhaps in the lid fragments). In this section the elemental composition of the four main materials that constitute the crucible fabric will be compared by crucible type (discussed in chapter 6.2.6) in order to identify any potential variation in manufacture (use of raw materials and their mixing) and/or operational practices.

The chemical composition average of the coarse external layers by crucible type is given in table 8.7. These reveal that there are some significant variations in composition between crucibles of different types. The biggest difference are in the Al_2O_3, SiO_2 and K_2O contents between type 1 and 2 crucibles. These patterns are presented visually in figures 8.26 and 8.27. Type 1 crucibles consistently have higher Al_2O_3, K_2O and lower SiO_2 contents, suggesting that the coarse external layers are made with different raw materials or at least varying mixtures of the same ingredients. Unfortunately, due to their highly vitrified nature, very little microstructural difference could be seen which could have helped identify specific ingredients. However, it could be attributed to the fact that type 1 crucibles appeared to have less quartz, hence the lower SiO_2 content and more glassy matrix, accounting for the increased Al_2O_3 levels. On the other hand, this does not account for the higher K_2O content.

The external layer chemical composition of type 3 crucibles is divided, with the two samples (20 and 31) from site PM75 showing closer similarities with crucibles of type 2. These have similar Al_2O_3, SiO_2 and K_2O contents but a little more CaO. Sample 33 from site PM103, on the other hand, has a closer composition to type 1 crucibles but with lower CaO content.

Table 8.7 - Average chemical compositions of the coarse exterior layer by crucible type. No – number of samples.

Type	No	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
1	11	0.7	1.4	14.3	68.7	0.3	BDL	4.4	5.8	0.5	BDL	3.8
	Std.Dev	0.2	0.4	2.2	5.4	0.2	-	0.9	2.4	0.1	-	1.0
2	11	0.5	1.0	6.9	80.0	BDL	BDL	2.1	4.4	0.5	BDL	4.4
	Std.Dev	0.1	0.3	1.6	3.4	-	-	1.3	2.1	0.2	-	3.4
3	3	0.4	0.7	10.7	73.9	BDL	BDL	2.7	7.3	0.6	0.1	3.6
	Std.Dev	0.4	0.2	4.3	1.7	-	-	1.5	5.0	0.1	0.1	0.5

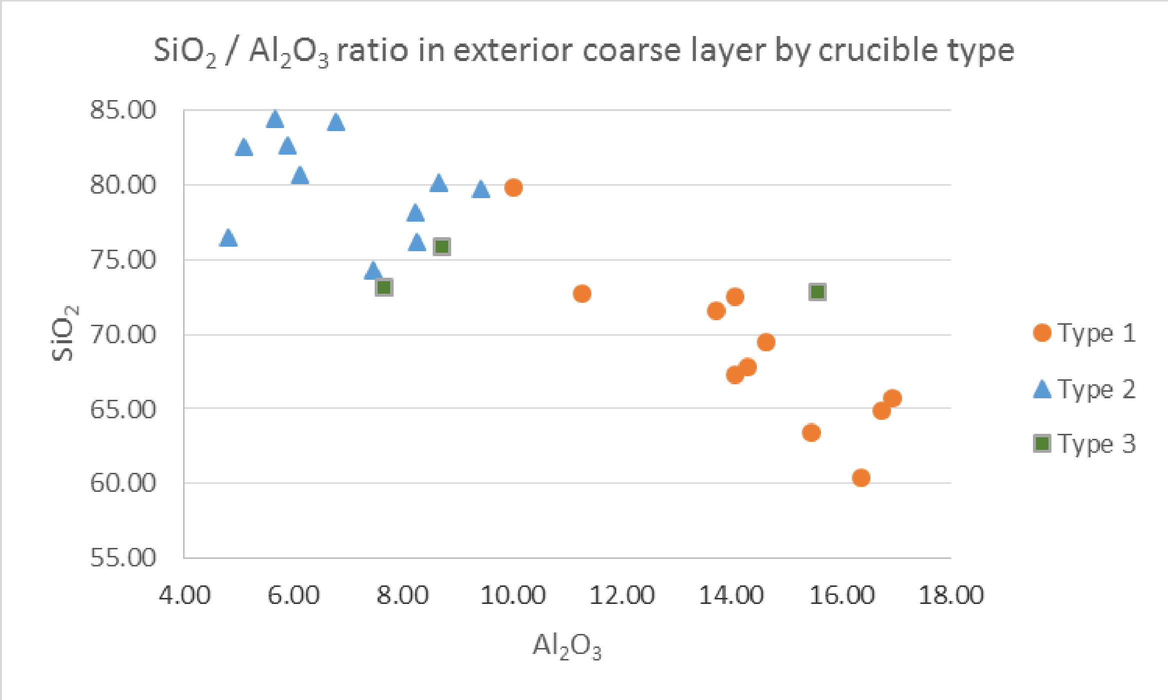


Figure 8.26 - SIO_2 / Al_2O_3 ratios in the exterior coarse layer by crucible type.

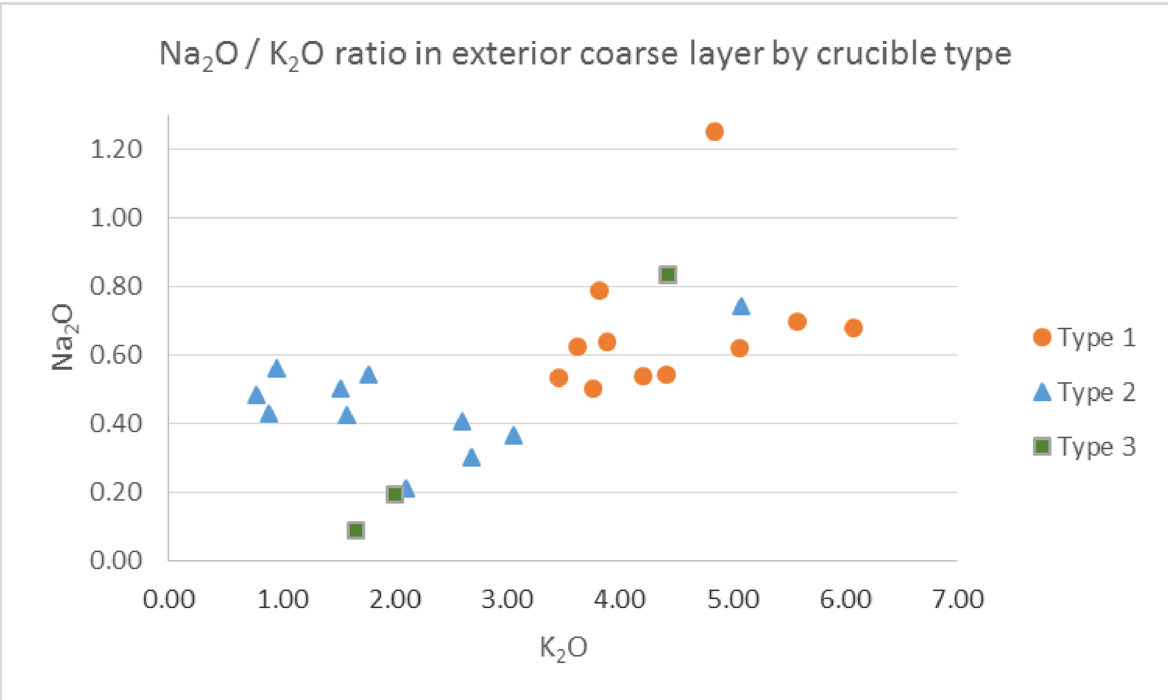


Figure 8.27 - Na_2O / K_2O ratios in the exterior coarse layer by crucible type.

As discussed above, the exterior coarse layer and lid compositions are very similar, suggesting that they are the same material. Taking this into account it is not surprising that similar compositional patterns between crucible types are also seen in the lid fragments. Although only one type 1 lid fragment was analysed, parallels are seen with the same higher Al_2O_3 and K_2O contents and lower SiO_2 levels than type 2 (Table 8.8, Figures 8.28 and 8.29). Unlike the external layer, which is totally vitrified, the lid microstructures support this trend, as the type 1 crucible (sample 23) proved to have an organic component. Indeed this would also account for the increased K_2O. Although it is not certain that this observation holds true for all type 1 lids, the similarity of the exterior layer composition of all type 1 samples to the lid fragment analysed suggests that they were all manufactured using the same or similar recipes. Unfortunately, no crucible type 3 lids were analysed but their coarse external layers suggests that the samples (29 and 31) from site PM75 were probably made with a similar recipe to the type 2 crucibles, while the sample (33) from site PM103 with a recipe close to that of the type 1 crucibles.

Table 8.8 - Average chemical compositions of the lids by crucible type. No – number of samples.

Type	No	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**SO_3**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**FeO**
1	1	0.5	0.9	12.7	73.8	BDL	BDL	3.0	1.7	0.4	BDL	7.0
	Std. Dev		N/A									
2	6	0.4	0.8	6.5	83.5	BDL	0.1	1.2	1.6	0.4	BDL	5.4
	Std. Dev	0.1	0.2	1.5	3.2	-	0.1	0.4	1.1	0.1	-	2.5

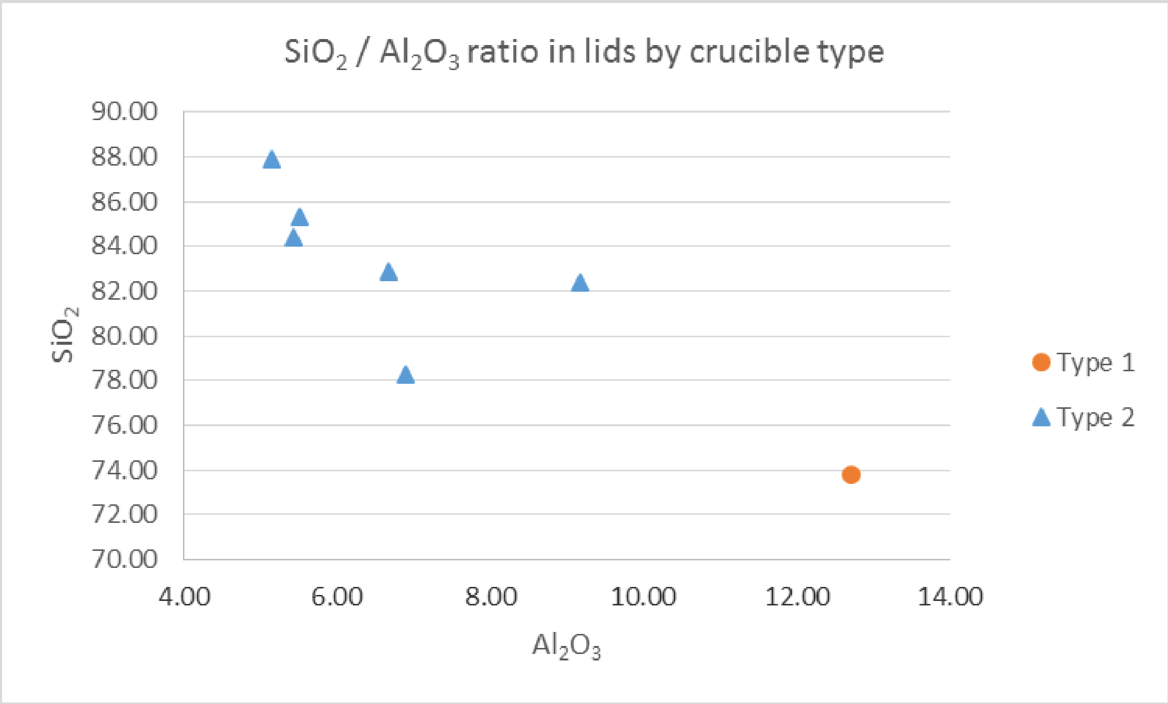


Figure 8.28 - SIO_2 / Al_2O_3 ratios in the lids by crucible type.

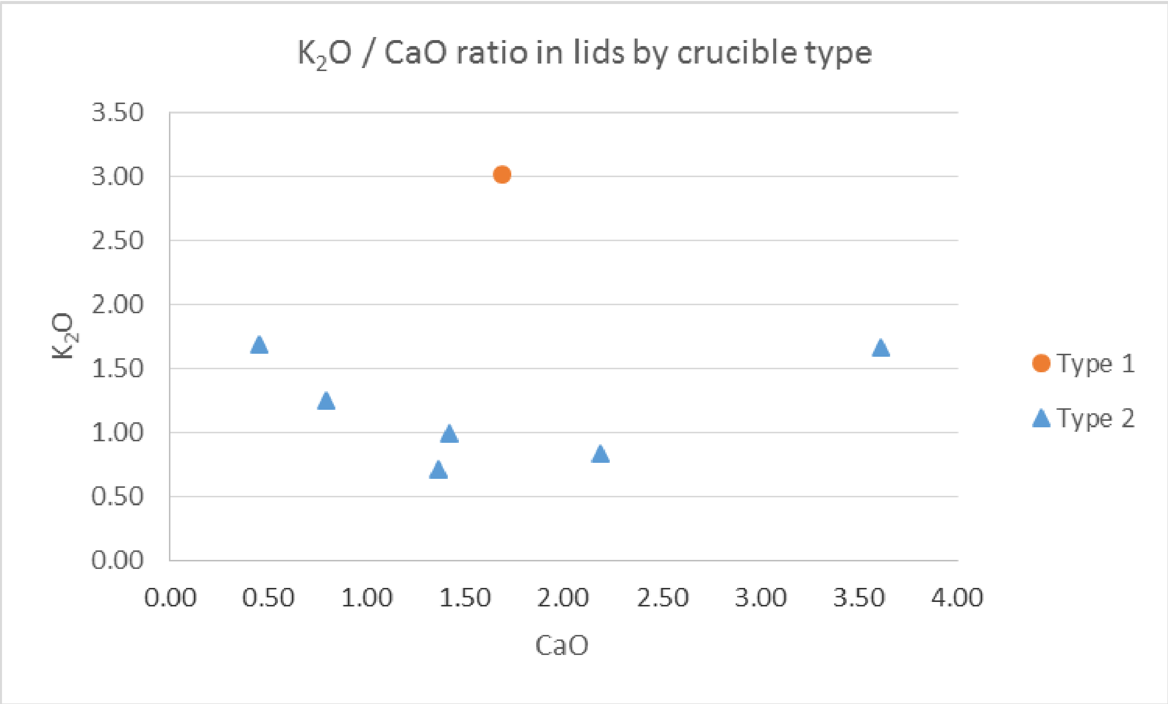


Figure 8.29 - K_2O / CaO ratios in the lids by crucible type.

The average chemical compositions of the main body fabrics by crucible type are given in table 8.9 and the individual sample average compositions illustrated in figures 8.30 and

8.31. It is evident that there is much less variation in the main body fabrics than in the external layers and lids. The difference between the three crucible types is not as well defined, with most elements equally represented. However, several aspects of their composition may be of interest. On the whole, type 2 crucibles tend to have lower SiO_2 and higher Al_2O_3 contents than type 1 and 3 (Figure 8.30). This may be explained by the fact that they appeared to contain fewer quartz crystals in their microstructure. Other distinct variations are seen in their overall lower K_2O and higher FeO levels (Figure 8.31). This may be attributed to the use of different clays but it is not something that was noticed microstructurally. The composition of type 3 crucibles also appear to be have closer parallels to that of type 1 rather than type 2 crucibles, suggesting that a similar clay was used. Although these small compositional variations are noticeable, it is clear that the recipe for the main body fabric was to a large extent standardised and reproduced throughout the whole region. This raises several questions as to who the artisans were and how crucible manufacture was organised. It is possible that the crucibles were manufactured by itinerant artisans who may have moved from site to site providing their services. Another possibility is that production was centralised and the crucibles traded or exported to localised steel production areas. Saying that, it is not inconceivable that the recipe was shared or passed down through generations by the group of people who manufactured them.

Table 8.9 - Average chemical compositions of the main body by crucible type. No – number of samples.

Type	No	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO
1	12	0.7	1.5	21.4	61.4	0.4	0.1	3.0	2.1	0.9	0.1	8.6
	Std. Dev	0.1	0.3	1.9	2.0	0.2	0.1	0.5	1.3	0.2	0.0	1.5
2	11	0.5	2.1	23.5	56.9	0.2	0.1	2.1	1.6	1.1	0.1	11.8
	Std. Dev	0.2	0.5	1.9	2.5	0.1	0.1	0.3	0.4	0.2	0.0	2.2
3	3	0.3	1.0	20.2	65.7	0.2	0.1	2.7	1.2	1.1	0.1	7.4
	Std. Dev	0.2	0.4	0.5	3.1	0.1	0.0	0.3	0.4	0.1	0.0	1.9

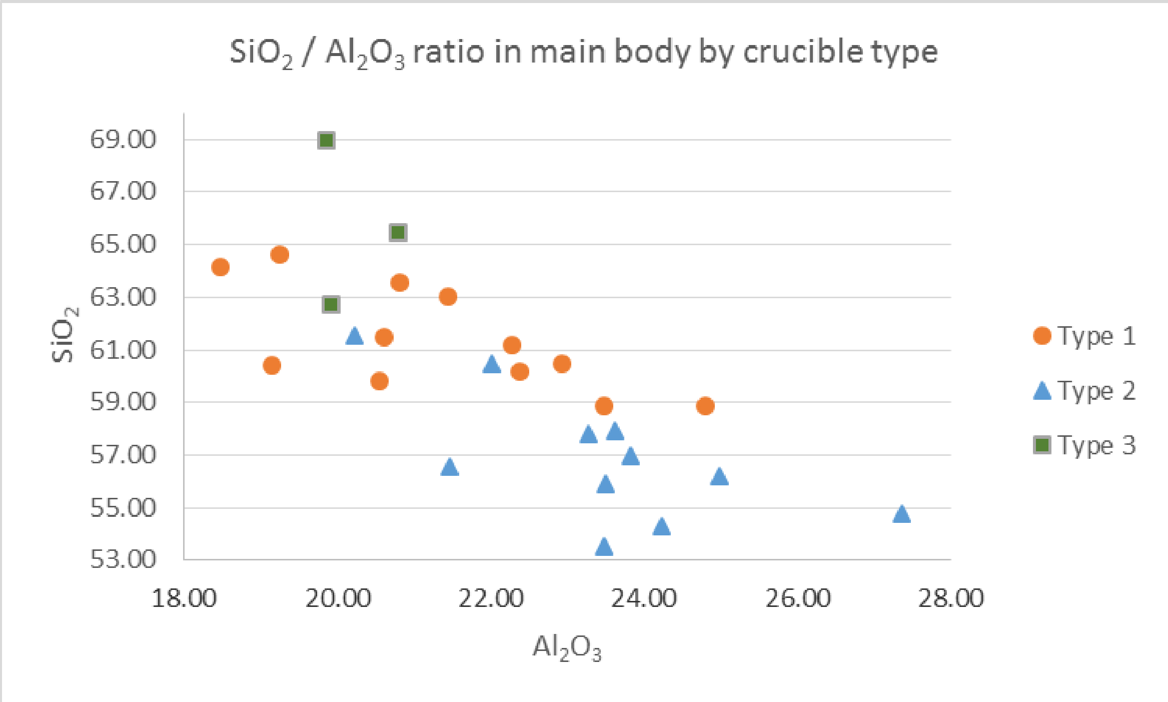


Figure 8.30 - SIO₂ / Al₂O₃ ratios in the main body fabrics by crucible type.

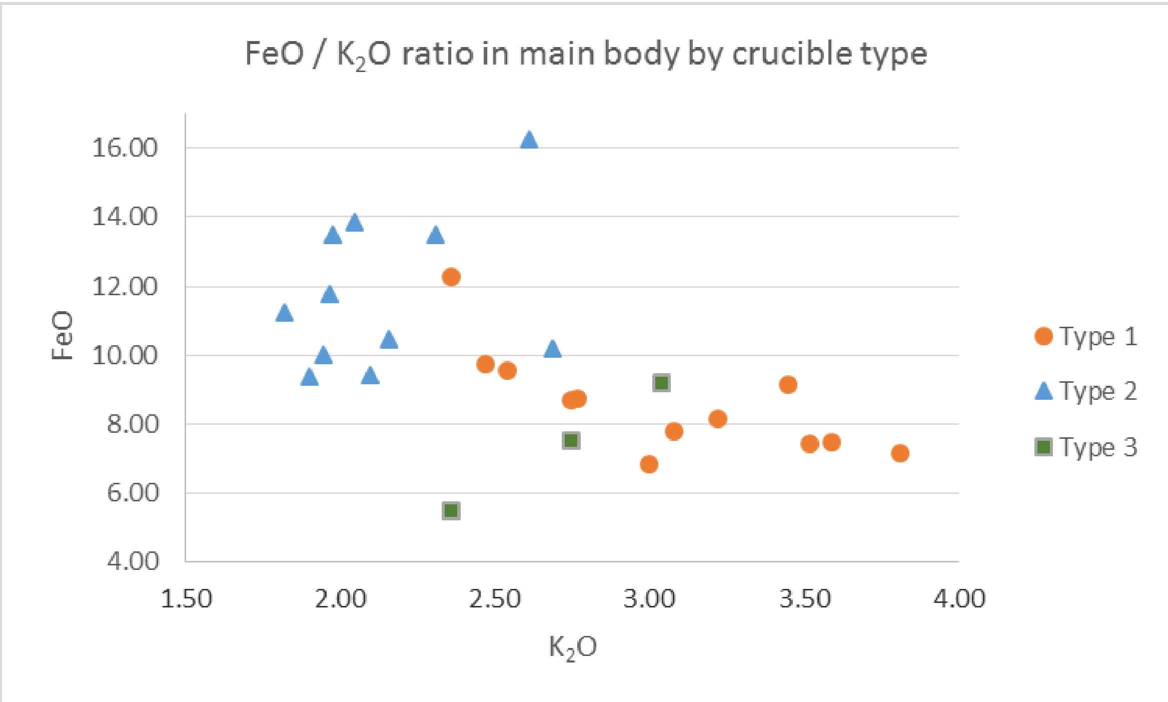


Figure 8.31 - FeO / K_2O ratios in the main body fabrics by crucible type.

The average chemical compositions of the glassy slags by crucible type are shown in table 8.10 and the individual sample average compositions illustrated in figures 8.32, 8.33 and

8.34. As mentioned in the previous section, the glassy slag compositions show most variation from sample to sample. This is not surprising as several interacting factors would have contributed to their composition. The lid and main body fabrics as well as the crucible charge (contents) are the likely contributions to the glassy slag and the amount of each that contributed cannot be easily determined by elemental analysis.

Although there are some overlaps, on the whole type 2 crucibles display higher SiO_2 and lower Al_2O_3 contents (Figure 8.32). This may indicate that the lid fabrics contributed more to the glassy slag composition than anything else, as the same pattern was observed in the former. The presence of quartz crystals in some of the type 2 glassy slags could account for this variation. Two hypotheses are possible, either the quartz came from the melting of the lids or sand was added to the crucible charge, but it is not possible to determine which at this stage. Although type 2 crucibles also tend to contain more MgO and less CaO than the other types (Table 8.10), these variations are not as clear, with significant overlap. The clearest trend is seen in the type 3 crucibles. The two samples (29 and 33) from site PM75 have significantly less Na_2O and more MnO than any others (Figure 8.33) while sample 33, from site PM103, has much lower CaO content (Figure 8.34). This could reflect a different technological process occurring on the type 3 sites, perhaps different ingredients were placed in the crucible. Since these sites are the most southerly in the research area, it is also possible that they were obtaining the ingredients comprising the crucible charge from different sources.

Table 8.10 - Average chemical compositions of the glassy slag by crucible type. No – number of samples.

Type	No	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**SO_3**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**FeO**
1	10	0.5	2.7	23.2	52.1	BDL	BDL	2.9	12.5	2.6	0.6	2.8
	Std. Dev	0.1	0.4	5.7	6.7	-	-	1.0	3.4	1.0	0.3	1.9
2	8	0.6	4.0	14.8	59.8	BDL	BDL	2.6	9.9	2.9	0.2	5.1
	Std. Dev	0.2	1.9	2.2	6.9	-	-	1.1	3.7	2.5	0.1	8.5
3	3	0.4	2.5	22.4	53.0	BDL	BDL	3.6	12.6	1.1	1.5	2.9
	Std. Dev	0.4	0.5	3.5	4.4	-	-	1.1	8.7	0.1	1.3	1.5

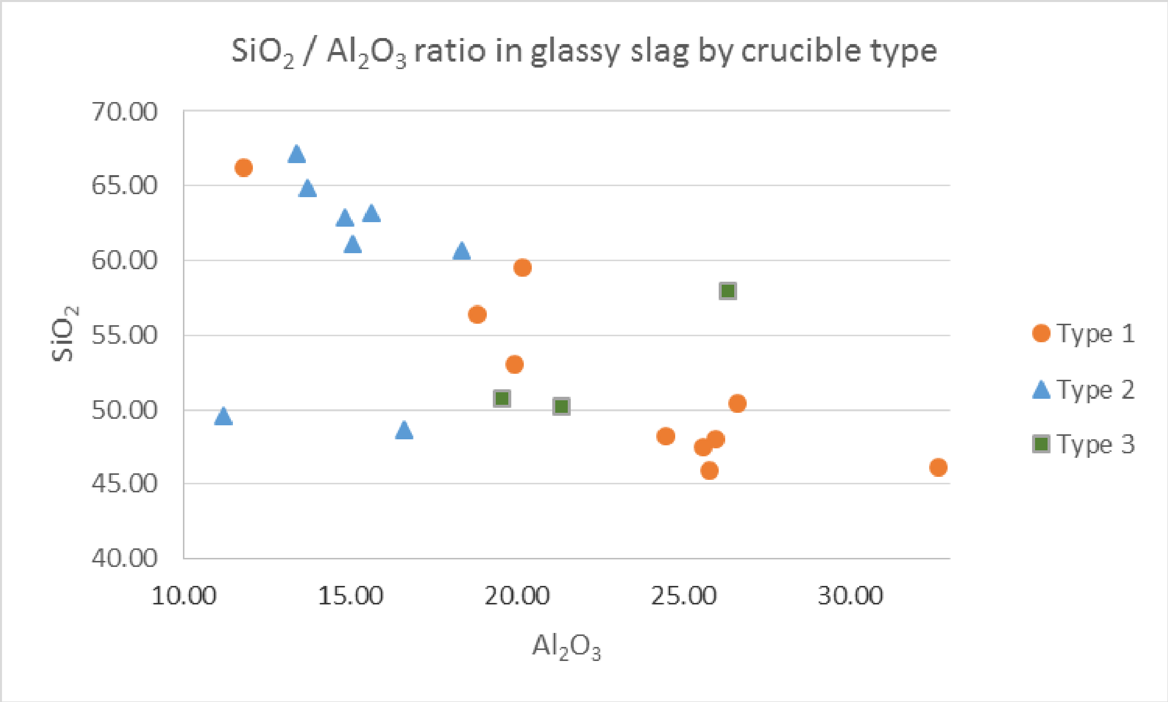


Figure 8.32 - SIO_2 / Al_2O_3 ratios in the glassy slag by crucible type.

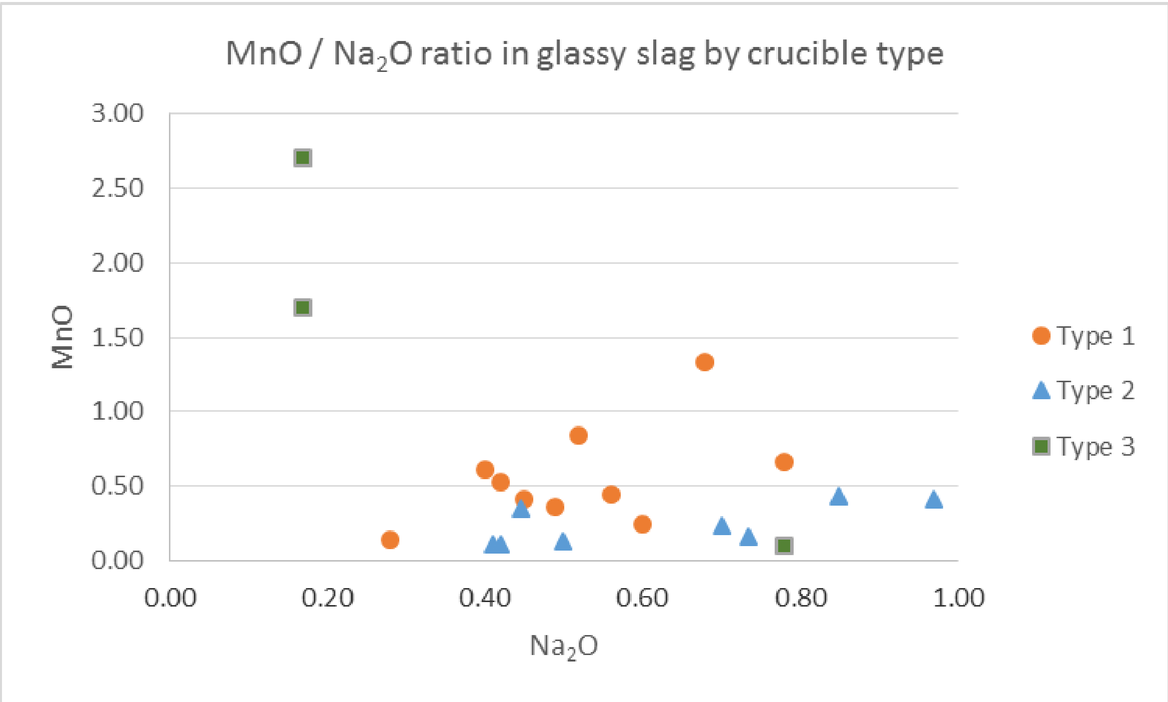


Figure 8.33 - MnO / Na_2O ratios in the glassy slag by crucible type.

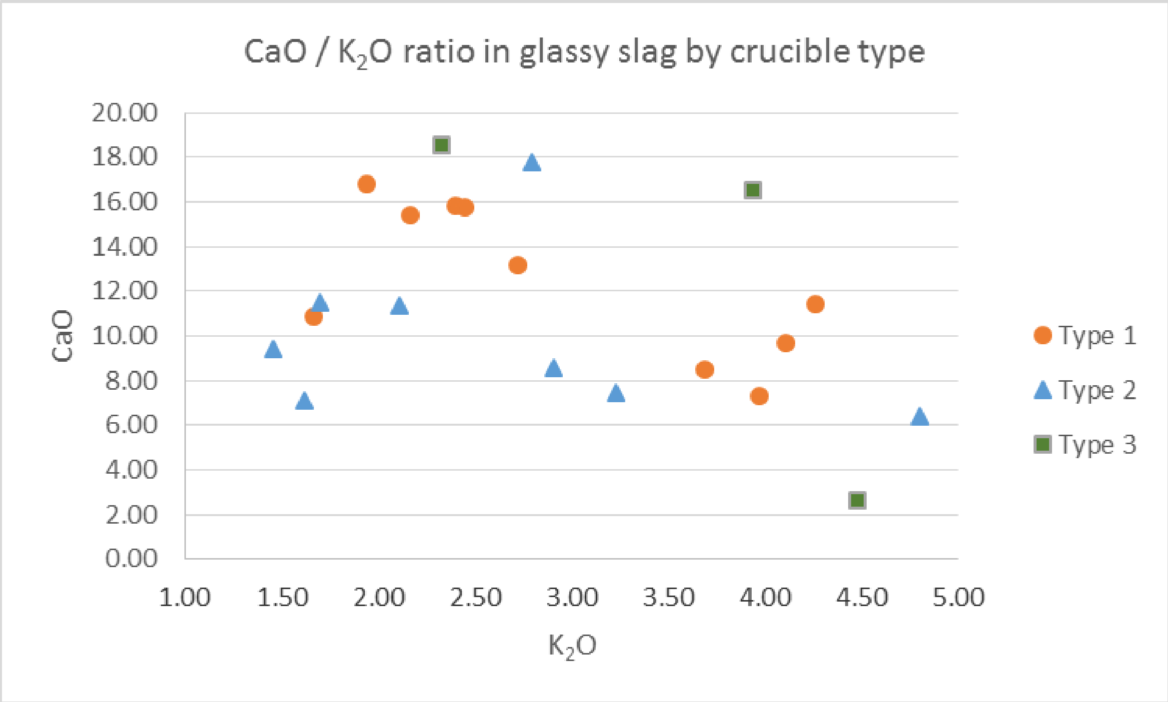


Figure 8.34 - CaO / K_2O ratios in the glassy slag by crucible type.

8.3.3 Comparisons with Other Central and South Asian Crucibles

In order to understand the nature of crucible steel production and the choice of materials and methods employed in Telangana, it is valuable to compare the scientific results and observations with those of other crucible steel production sites across Asia. As discussed earlier (chapter 2), only a few crucible steel production areas are currently known, primarily distributed in Central and South Asia. Crucible remains and glassy slag fragments from several of these sites have been analysed and published. This includes material from Merv, Akhsiket, Pap, Termez and Chāhak in Central Asia, Gattihosahalli in South India and Mawalgaha in Sri Lanka. All data for Termez and Mawalgaha was taken from Rehren and Papachristou (2003, 396), data for Chāhak from Alipour and Rehren (2014, 248-9), data for Gattihosahalli from both Rehren and Papachristou (2003, 396) and Freestone and Tite (1986, 44), while the Merv glassy slag data was used in part from Merkel (2013, 247). The remaining data (particularly for Merv, Akhsiket and Pap) comes from Feuerbach's (2002) unpublished thesis. In order to enable comparisons with the Telangana data presented in this study, all datasets taken from these sources were normalised to 100%.

Before the chemical compositions of the main crucible body fabrics can be discussed, it is important to briefly mention the microstructural observations from the main production sites. All crucibles can be broadly characterised into two main groups – those tempered with quartz and those tempered with rice husks. This difference seems to provide the preferred manufacturing methods between Central Asian crucibles (Uzbekistan/Turkmenistan/Iran) and South Asian crucibles (South India/Sri Lanka) respectively. This also undoubtedly accounts for the most striking visual differentiation between these two groups, the colour and consistency of the crucible ceramic – dense white/grey in Central Asia and porous black in South Asia (Rehren and Papachristou 2003, 400). Although the carbon content of the ceramics are rarely quantified (primarily due to the detection limitations of analytical equipment) it is not unreasonable to suggest that the burnt organic material in the crucibles of South Asia produced more carbon than their Central Asian counterparts, hence explaining their black appearance. This is supported by Balasubramaniam *et al* (2007, 661) and Srinivasan (2007, 681), who suggest that the rice husk inclusions would have contributed a significant amount of carbon.

The microstructures of the main crucible body ceramic of Central Asian sites has been reported in several publications. The crucibles from Uzbekistan are apparently very similar to one another in microstructure. The Akhsiket crucibles are dominated by a glassy matrix comprising mullite and cristobalite, with a fine quartz temper amounting to roughly 50% by volume (Papakhristu and Rehren 2002, 70; Rehren and Papakhristu 2000, 56-7). The crucibles from Pap, Kuva and Termez are almost identical in microstructure to the Akhsiket examples (Rehren and Papachristou 2003, 397). The crucibles from the main Turkmenistan site of Merv are reported to be similar to the other Central Asian sites (Rehren and Papachristou 2003, 397), with a glassy matrix dominated by mullite and crystobalite with inclusions of feldspars, zircon and quartz (Feuerbach 2007, 324; Feuerbach *et al* 1997, 106; 1998, 41; 2003, 261). However, the quartz temper appears to be less dominant in the Merv crucibles, accounting for approximately 10% by volume and there is additional evidence which points to grog inclusions in the ceramic fabric (Feuerbach 2007, 331; Rehren and Papachristou 2003, 397). The microstructural analysis of the Chāhak crucibles has yet to be published in full (Alipour and Rehren 2014, 247).

The crucibles from South Asia differ considerably. The crucibles from Gattihosahalli are made of a ferruginous clay heavily tempered with rice husk and straw (Anantharamu *et al* 1999, 18). The fabric is described by Freestone and Tite (1986, 54) as having irregular voids containing skeletal material representing the original rice husk. Indeed, the micrographs provided in their study shows almost identical features to those seen in Telangana. This is paralleled with crucibles found in the Tamil Nadu state of South India. Srinivasan (2007, 681) describes the main fabric of crucibles from Mel-siruvalur and states that they are black in colour, porous, very carbonaceous with tiny pieces of charcoal, and that they consisted of a glassy network with distinctive coked rice hull relics dispersed in the matrix. She also agrees that there are close similarities with the other South India crucibles from Telangana and Gattihosahalli. Few analyses have been done on the Mawalgaha crucibles but investigation by Wayman and Juleff (1999, 29) describe them as being uniformly black in colour and made of a mixture of rice husk and clay. Hence the similarities to all other South Asian crucibles is obvious (Rehren and Papachristou 2003, 400).

The average chemical composition of the main crucible body fabrics by site is provided in table 8.11, while figures 8.35, 8.36 and 8.37 show the average elemental ratios of individual samples analysed from each site in comparison with the Telangana material. Several patterns can be identified. For the most part, the Telangana material has lower Al_2O_3 and SiO_2 content than all other examples (Figure 8.35) and perhaps more significant they are higher in Na_2O, MgO, CaO, TiO_2 and FeO (Figures 8.36 and 8.37). The Telangana examples have as much as four to ten times more FeO than their Central Asian counterparts, suggesting that a more ferruginous clay was used. The higher MgO, CaO and TiO_2 content may also be attributed in part to the rice husk temper, as the analysis of these regions showed significant traces of these elements. This is also supported by the fact that the other South Asian sites of Gattihosahalli and Mawalgaha have comparable contents of the same elements (particularly high FeO and CaO - Figure 8.37). It is noticeable that the crucibles of both sites are not only very similar to one another but are almost identical to those of the two Telangana type 3 fragments analysed from site PM75. This is more clearly represented in figure 8.36 which shows the very similar MgO/Na_2O ratios. It can therefore be argued that the South Asian crucibles represent a different approach to crucible manufacture than their Central Asian counterparts. In saying that, it must be mentioned that the Chāhak crucibles are to some extent more comparable in composition to the South Asian examples, particularly in CaO and FeO content. The similarity in microstructure and chemical composition of all the South Asian crucibles must in some way reflect contact and transfer of knowhow between these areas, which may have resulted in the spread of crucible steel technology. Indeed, the history of South India (Sastri 1975) clearly points to strong contacts between South India and Sri Lanka as early as the Iron Age.

Table 8.11 - Average chemical compositions of all (published) main crucible body fabrics (not including lids, external layers or bases) from all major Central and South Asian sites. All data for Merv, Akhsiket and Pap were taken from Feuerbach (2002), data from Termez, Gattihosahalli and Mawalgaha were taken from Rehren and Papachristou (2003, 396), and data for Chahak was taken from Alipour and Rehren (2014, 248). All data normalised to 100%. No – number of samples.

Site/Region	No	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO	V_2O_5
Merv	2	0.2	0.2	23.0	70.2	-	-	4.3	0.4	0.5	-	1.3	-
Akhsiket	7	0.3	0.6	29.3	63.1	0.2	0.0	2.8	0.4	0.7	0.0	2.5	0.1
Pap	3	0.3	0.6	29.3	63.1	0.2	0.0	2.8	0.4	0.7	0.0	2.5	0.1
Termez	1	0.5	0.5	32.8	61.5	-	-	2.3	1.0	0.3	-	1.0	-
Chāhak	6	0.5	0.7	25.7	63.1	-	-	1.4	1.3	1.6	0.8	5.9	-
Gattihosahalli	1	0.1	0.8	25.4	62.9	-	-	2.5	1.4	0.8	-	6.1	-
Mawalgaha	1	0.1	0.9	24.0	64.1	-	-	2.2	1.8	0.8	-	6.0	-
Telangana All	26	0.6	1.7	22.1	60.0	0.3	0.1	2.6	1.8	1.0	0.1	9.8	-

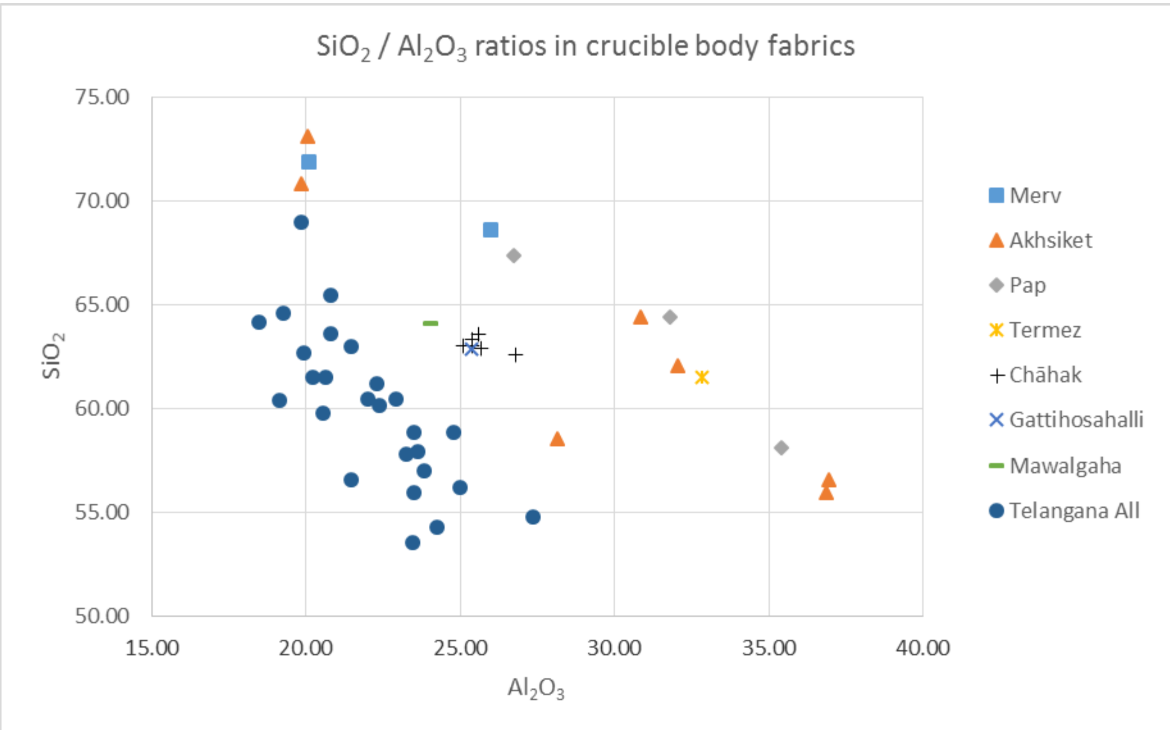


Figure 8.35 – Average SiO_2 / Al_2O_3 ratios of all crucible body samples published from Central and South Asian sites.

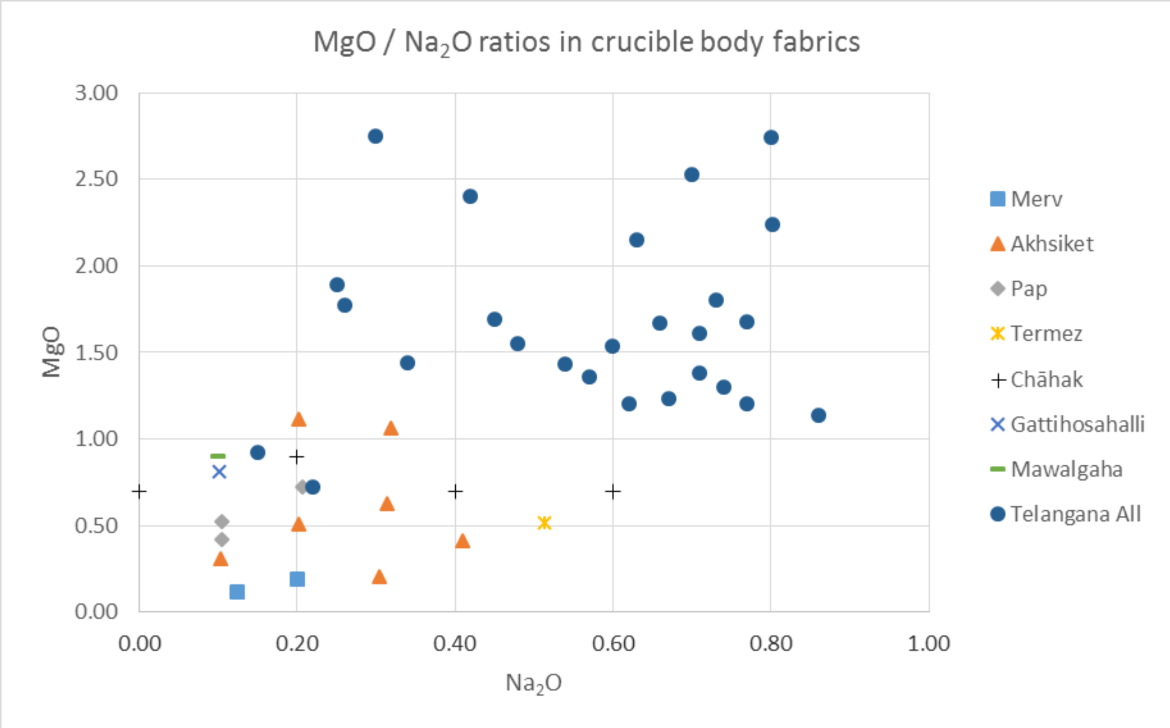


Figure 8.36 – Average MgO / Na_2O ratios of all crucible body samples published from Central and South Asian sites.

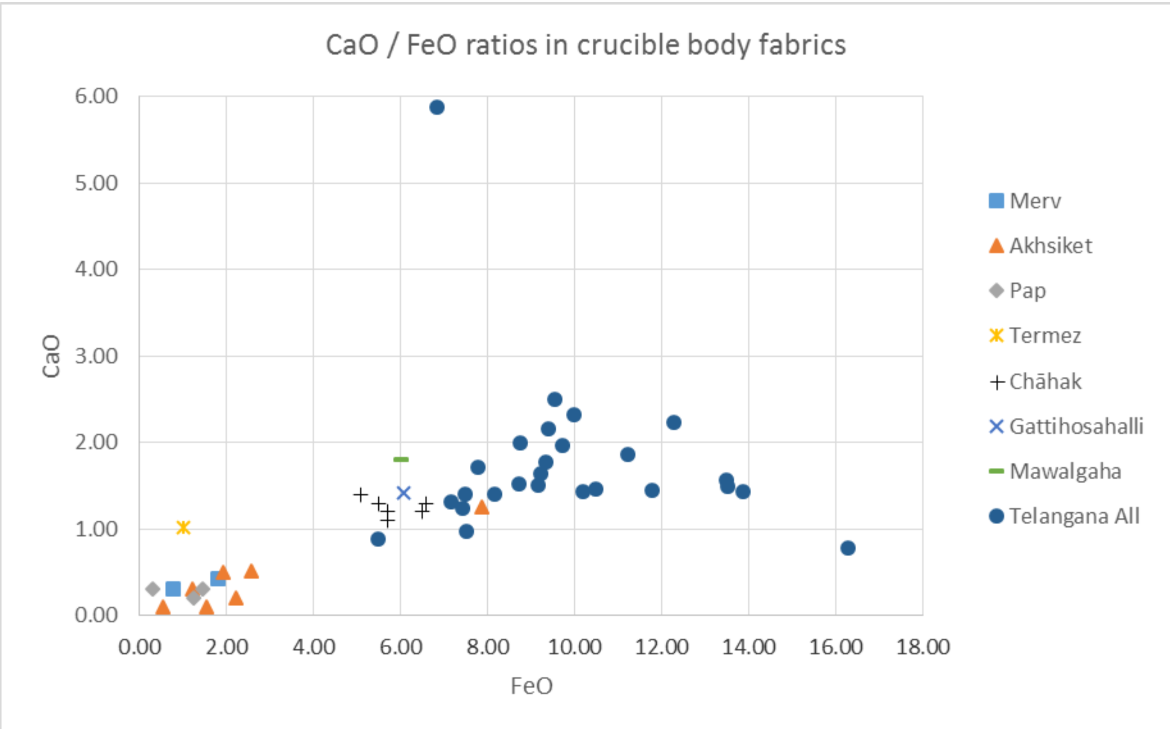


Figure 8.37 – Average CaO / FeO ratio of all crucible body samples published from Central and South Asian sites.

Very few compositional analyses of the internal crucible glassy slags have been published and none to date for any of the South Asian sites. This gap in knowledge was one of the main reasons for the analysis of the Telangana glassy slag in this study. Another motive was the fact that crucible steel production in the Telangana region is believed to have employed the co-fusion method which differs from the carburisation method suggested for all other regions and sites. This is discussed in more detail in chapter 2. What is important here is that this assumption of co-fusion is based solely on one historical description of the process at the site of Konasumudram (site PM65 in this study) by Voysey (1832). Bronson's (1986) seminal review of documentary sources for the production of crucible steel cemented this as fact and the process employed in Telangana has not been in question since. However, in light of new evidence there is now some scope for challenging this. Descriptions of crucible steel manufacture by Havart (1693) almost a century and a half before Voysey's account appears to describe a different process in Telangana (see chapter 2.2.3). The glassy slag within the crucibles is the waste material primarily left over from the original charge (as well as the melting of the crucible body and lid). The analysis of this waste provides the best chance to identify the contents of the crucible or at least present enough compositional variation from other sites to enable discussion.

Before the chemical compositions are discussed, it is important to briefly describe the nature of the glassy slag material from each site. More detailed descriptions of the crucibles are outlined in chapter 2 so just brief outlines of the glassy slags with published compositional data will be dicussed here. The glassy slag from Akhsiket is typically 2-8cm thick, situated 15-20cm above the base. It is highly porous with spherical voids up to 2cm diameter, comprising on average half of the volume of the glassy slag. The colour ranges from opaque brown, grey, turquoise, bright blue and translucent dark green (Feuerbach 2007, 330; Rehren and Papakhristu 2000, 57). Beneath this slag cake is a typical honeycomb (porous) layer of slag adhering to the crucible wall where the steel ingot would have solidified (Papakhristu and Rehren 2002, 70). The glassy slag found in the crucibles at Pap are almost identical to those from Akhsiket (Rehren and Papakhristu 2003, 397). The slag in the Merv crucibles is very different. It tends to be thinner, forming a ring or fin 8-10cm from the base. There is also a thin honeycomb slag layer below the fin adhering to the crucible body where the steel ingot solidified (Feuerbach 2007, 323). The slag is glassy with no notable crystalline inclusions and ranges in colour from shiny green to a darker, dull bluish-green (Feuerbach *et al* 1997, 107; 2003, 261). The Chāhak crucibles have glassy slag more consitent with those from Merv, being relatively thin (<1cm), glassy or opaque and dark or light green in colour. There is also a thin layer of rough slag adhering to the internal crucible surface below the slag fin (Alipour and Rehren 2014, 244). There are several major differences between internal glassy crucible slags from Central Asia and those observed in Telangana. The crucibles from Akhsihet and Pap contain considerably more slag than any other site, while all Central Asian glassy slags are varying shades of blue and green as opposed to the black colour of all Telangana examples.

The average chemical composition of glassy slags from the Central Asian sites and Telangana are given in table 8.12, while the average elemental ratios of individual samples from each site are shown in figures 8.38, 8.39, 8.40 and 8.41. This shows that many of the glassy slags from all sites have a certain degree of overlap in elemental content. It is clear that the Telangana material has similar overall compositions to those of the Central Asian sites, with comparable Na_2O, Al_2O_3, SiO_2, K_2O and CaO contents (Figures 8.38 and 8.39) and similar MgO contents to the Merv and Chāhak slags (Figure 8.40). However, there is significant variation in TiO_2 and MnO content. The Telangana slags have on average five times more TiO_2 and comparitively low MnO content (Table 8.12 and Figure 8.41). This suggests that there was some difference in process and that different materials were placed in the crucibles.

The elevated MnO content in the Central Asian crucible slags may be attributable to the addition of 'magnesia' (interpreted as manganese oxide by Alipour and Rehren 2014) which is often stated as a charge componant in historical accounts (Alipour and Rehren 2014, 257). In contrast, no historical account in South Asia describes the addition of magnesia. The higher TiO_2 levels in the Telangana slags could be related to the use of iron smelted from ores rich in TiO_2. In this case, the slag inclusions trapped within the metal would certainly have had elevated TiO_2 contents and contributed to the glassy slag inside the crucibles. Another consideration is Voysey's (1832) account which describes the placing of ore directly within the crucibles. Lowe's (1995) analyses of a magnetite ore sample from Telangana revealed parts with up to 2.59wt% Ti which supports this argument. However, some of the internal glassy slags from Telangana had considerably less TiO_2. It is also significant that

Lowe does not report any Ti from the analyses of lateritic ores from the same region. Therefore, it is possible that there is a link between Ti content in crucible slags and what ore was used, either to smelt the iron used in the process or placed directly in the crucibles as Voysey suggests. This cannot be resolved within the scope of this study but should be addressed in future studies.

On the whole, the internal crucible slag results are not sufficiently conclusive to validate a clear difference in steel manufacturing process (carburisation or co-fusion). If plant or wood material was placed within the crucible on the Central Asian sites, as would be the case in the carburisation process, then one might have expected greater CaO, K_2O and MgO contents (the major constituents of plant/wood ash – Sanderson and Hunter 1981) than those found in Telangana, which are believed to have used a co-fusion method (Bronson 1986; Lowe 1995). In fact, considerably lower CaO, K_2O and MgO contents are reported for the Akhsiket slag than those found in Telangana (Table 8.12, Figures 8.39 and 8.40). However, the possibility that some sort of flux was used in the Telangana process cannot be ruled out, which may have compensated for lower contents of these elements. Voysey (1832) for example, mentions the introduction of ore and *kanch* (glass formed in the process – presumably glass from previous firings). Conversely, fluxes may have been added in the Central Asian processes. The addition of limestone (primarily CaO), granite (primarily SiO_2, Al_2O3 and K_2O), sand (SiO_2) or blast furnace slag is proposed by Merkel (2013) for steel production at Merv. The seemingly infinite possibilities and variations of potential ingredients used to manufacture crucible steel as well as conflicting historical accounts makes it hard to pin-point the exact processes employed at these sites.

What is clear is that further research needs to be conducted *vis-a-vis* the nature of the crucible contents and the slag found within the crucibles. The analysis of the internal glassy slags in the other South Asian sites would be a good starting point and may reveal more on the raw ingredients employed in the manufacture of crucible steel. In addition, *in situ* experimental crucible steel making programmes using local resources would help greatly in validating or refuting certain hypotheses generated by the analysis of the archaeological remains. This should include testing variations in crucible charge (co-fusion and carburisation), followed by in depth macro and microstructural analysis of the waste material and final product. The results could then be compared to the archaeological remains.

Table 8.12 - Average chemical compositions of all (published) glassy slags from Central and South Asian sites. All data for Akhsiket and Pap were taken from Feuerbach (2002), data for Merv was taken from both Feuerbach (2002) and Merkel (2013, 247), and data for Chahak was taken from Alipour and Rehren (2014, 249). All data normalised to 100%. No – number of samples.

Site	No	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	Cr_2O_3	MnO	FeO	V_2O_5	BaO
Merv	30	0.3	3.0	17.0	50.8	0.0	0.1	3.4	17.0	0.6	-	5.9	1.6	0.1	0.4
Akhsiket	6	0.3	0.8	13.3	58.4	0.2	0.0	1.5	10.1	0.3	-	11.7	2.8	0.1	0.5
Pap	3	0.6	1.0	18.6	64.2	0.3	0.0	2.5	7.9	0.6	-	1.1	2.9	0.1	0.1
Chāhak	8	0.5	3.0	16.3	46.0	-	0.7	1.5	15.2	1.0	-	13.3	2.8	-	-
Telangana	21	0.5	3.2	19.9	55.2	0.1	0.1	2.9	11.5	2.5	0.9	0.6	3.7	-	-

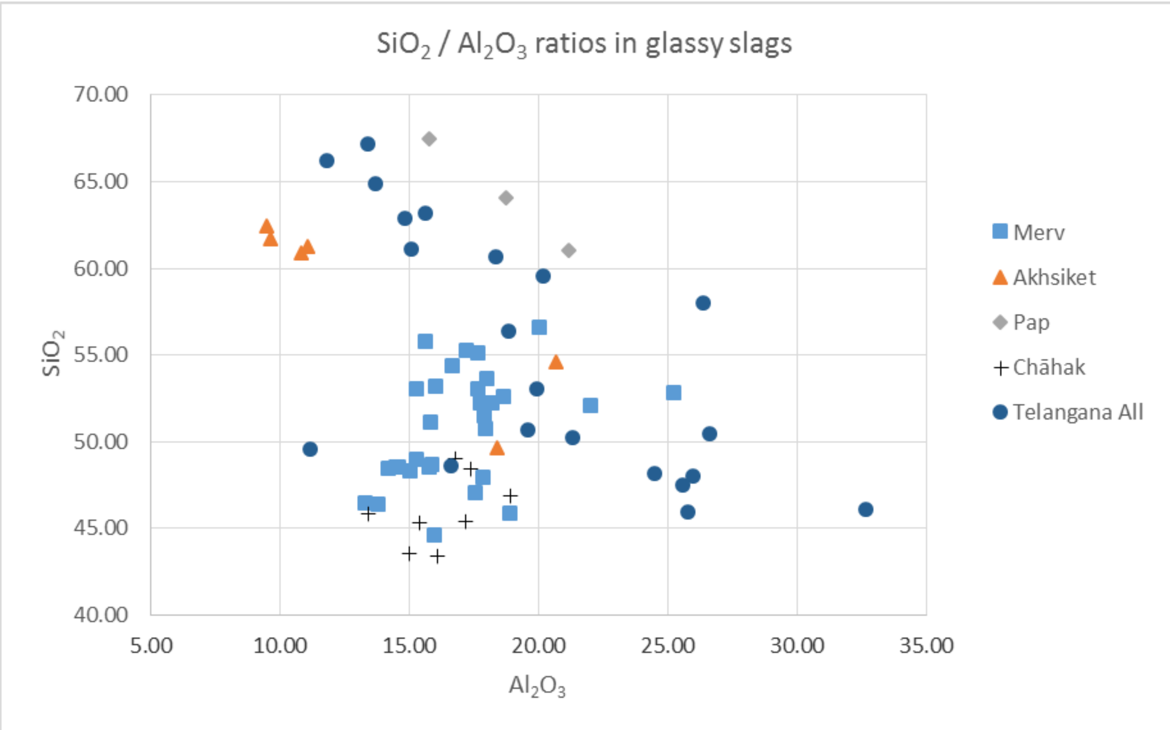


Figure 8.38 - Average SiO_2 / Al_2O_3 ratios of all internal crucible slag samples published from Central Asia in comparison to those from Telangana.

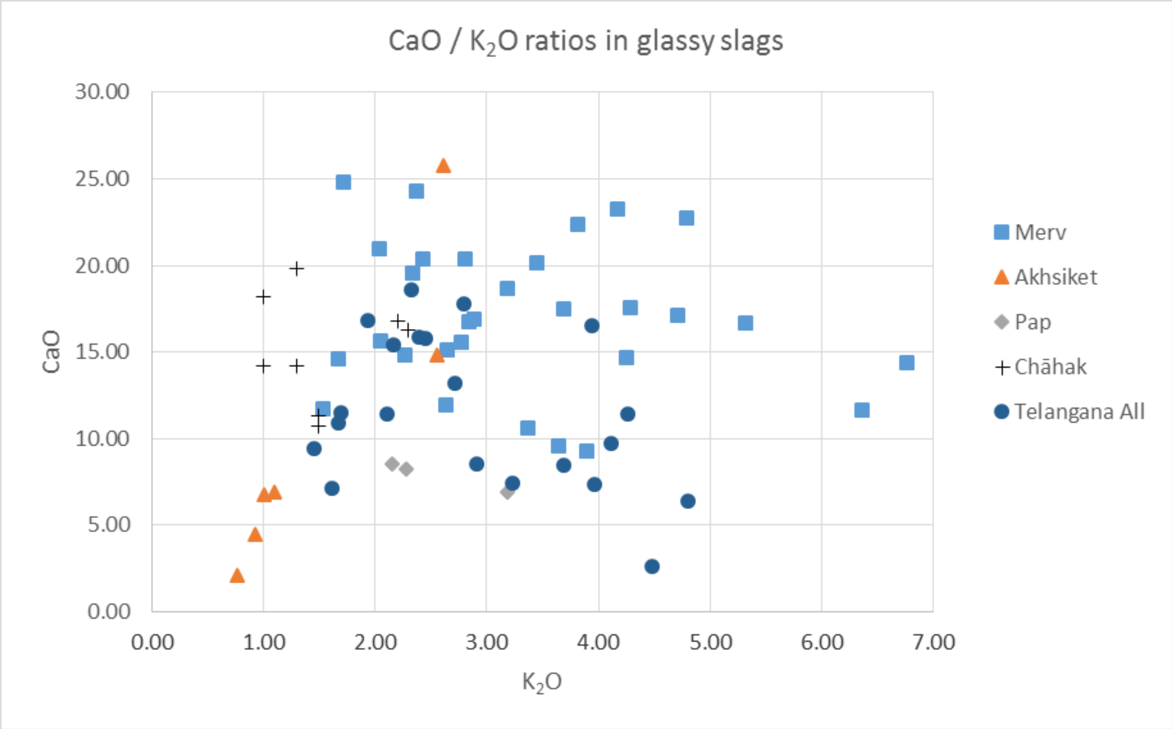


Figure 8.39 - Average CaO / K_2O ratios of all internal crucible slag samples published from Central Asia in comparison to those from Telangana.

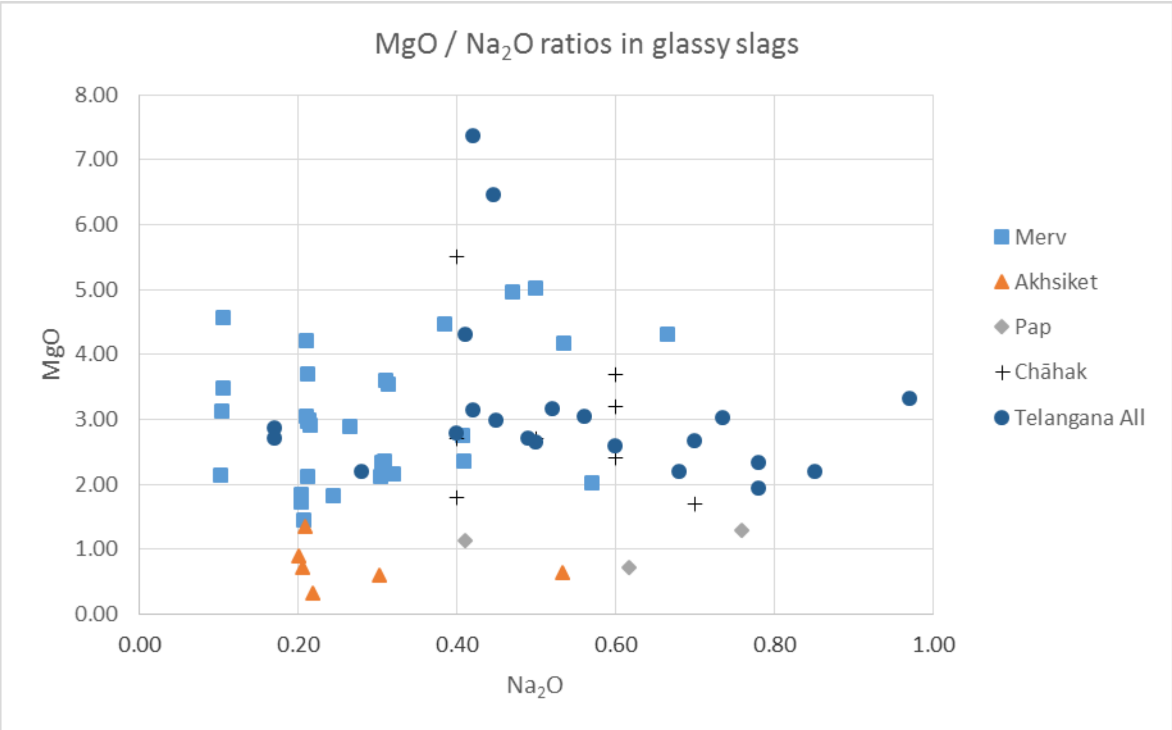


Figure 8.40 - Average MgO / Na_2O ratios of all internal crucible slag samples published from Central Asia in comparison to those from Telangana.

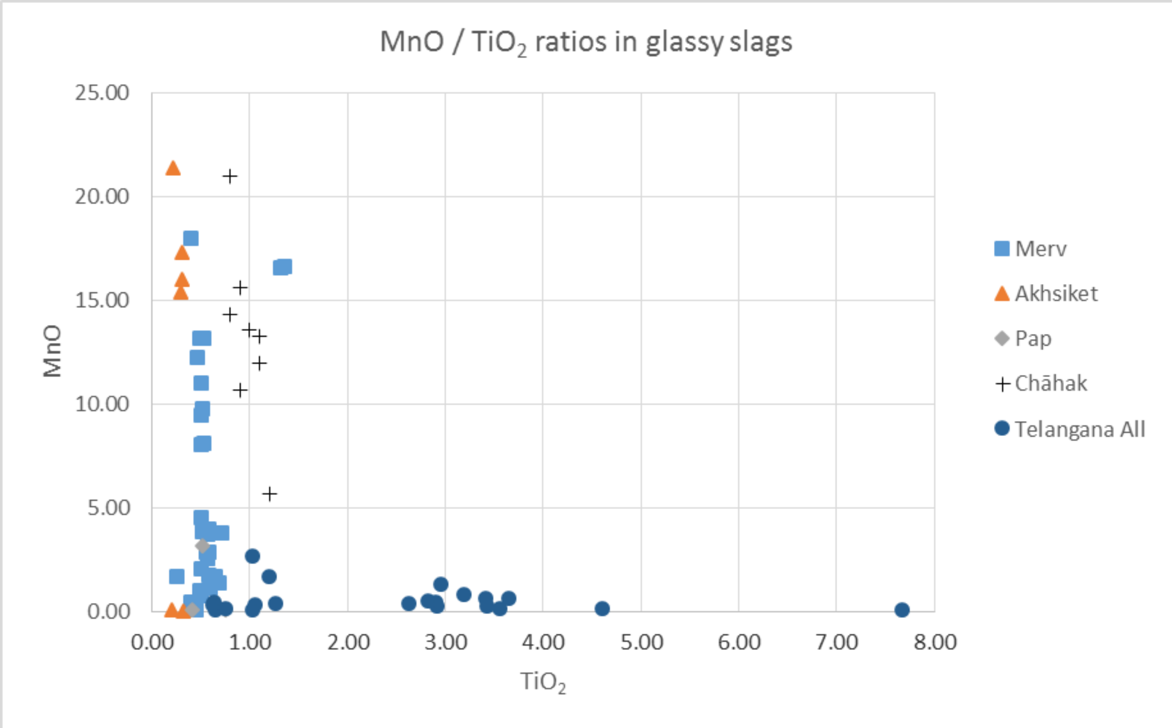


Figure 8.41 - Average MnO / TiO_2 ratios of all internal crucible slag samples published from Central Asia in comparison to those from Telangana.

Another feature which may be compared with other production sites are the metallic prills commonly found within the internal glassy slag and the upper parts of the crucible wall surfaces (or base of lids). These crucible prills have been reported from all Central and South Asian sites and in a few instances they have been analysed. These prills are believed to have 'splashed' onto the upper parts of the crucibles due to 'carbon boil' of the crucible charge (Feuerbach *et al* 2003, 262) and have hence been taken as representative of the material melted in the crucibles (Srinivasan 2007, 682; Srinivasan *et al* 2009, 118). The prills analysed from Merv (Feuerbach et al 1997, 108; 2003, 262) and Mel-siruvalur (Srinivasan 2007, 682-3; Srinivasan *et al* 2009, 118-9) are mostly high-carbon hyper-eutectoid steel or steel dominated by pearlite, with an average carbon content of >0.8%. Cast iron microstructures were also observed in some of the prills from Merv (Feuerbach *et al* 1997, 108; 2003, 262). This is comparable to the prills analysed in this study which for the most part also display hyper-eutectoid microstructures, suggesting a carbon content of >1wt%.

In terms of chemical composition, it becomes difficult to compare the analyses between sites as many have not been published fully. It is also commonly accepted that prills found in the glassy slags invariably contained some elements taken from the surrounding glassy melt (Feuerbach 2007, 327). Nevertheless, it may be significant that prills from Merv contained as much as 0.3wt% Mn, with detectable levels of P (Feuerbach 2007, 328-9) which is comparable to some of the prills analysed in the Telangana crucibles. The prill analysed from Mel-siruvalur contains much higher P content, as well as Ni, Ca and S (Srinivasan 2007, 682; Srinivasan et al 2009, 118). Prills from both sites also contained significant Cu, which was not detected in the crucibles from Telangana. Prills in the Chāhak crucibles had elevated Cr contents up to 12.1wt% (Alipour and Rehren 2014, 249) which was also not detected in those from Telangana. Although small variations in elemental composition are expected from crucible steel produced on different sites, it is evident that all these sites produced high-carbon steel.

8.4 Conclusion

In all 26 crucible fragments were analysed from sites located in Northern Telangana. Care was taken to ensure these were not only representative of the assemblage as a whole but also included all material layers of the crucibles themselves; the coarse exterior coating, the crucible main body, the internal glassy slag and the lid. The importance of such analyses lies in the fact that no study to date as tackled detailed scientific analysis of a wide range of crucible samples from the Telangana region and no quantitative elemental analyses of the various material layers (composing the crucible) have been published. The results were then probed for trends identifying variation or lack of between the different material layers, the three morphological types of crucible as well as comparisons with other crucible production sites in Central and South Asia.

The microstructural and elemental data showed very little variation in composition and manufacture of the crucibles from Telangana. The main bodies were all made of a fine ferruginous clay, heavily tempered with rice husks. No major variation between crucibles of the three different types was observed, except perhaps a slightly higher quartz content in type 1 and type 3 crucibles. This would also account for the moderately lower SiO_2 and higher Al_2O_3 content of the type 2 crucible fabrics.

The exterior layer and lids proved to be the same material, a coarse quartz-rich clay. This suggests that the exterior coating of the crucibles was applied at the same time as the lid plug, whereby excess material was smeared on the exterior surfaces to protect it from the high operating furnace temperatures (see chapter 6.2.6). Some variation in chemical composition was noticed in this material, showing differences in composition between crucibles of type 1 and type 2. The lid fragment microstructures observed suggest that the type 1 crucibles employed a different clay or clay mixture with a significant organic component not noticed in the type 2 crucibles. This further emphasises the validity of the proposed morphological types and suggests some minor process variation between crucibles of different types.

Most variation was seen in the internal glassy slags, which show fluctuating elemental compositions. However, this variation showed no relevant trends pointing to differences in process or crucible charge between the different crucible types. This was partly interpreted as the inability of the worker to control all aspects of the process and of course the formation of the internal crucible slag itself. Glassy crucible slags could be a by-product of the vitrification of the crucible body and lid fabrics and/or derived from the crucible charge, either unintentionally from slag inclusions trapped in the metals or deliberately by the addition of other materials acting as flux. Deconvoluting this through compositional analyses of the glassy slag is difficult and it was not possible to identify by which process (co-fusion or carburisation) crucible steel was made in Telangana. Nevertheless, the elevated CaO contents of the glassy slag in most samples suggests that a Ca-rich 'flux' was added to the charge, perhaps limestone which has been found on some of the metallurgical sites.

The comparisons to crucibles from other Central and South Asian sites identified some interesting trends. The main crucible body fabrics were unsurprisingly very similar to other South Asian sites (Gattihosahalli and Mawalgaha), which are also made of rice husk-tempered ferruginous clay. Perhaps of more interest is the fact that the crucibles from site PM75, which is the most southern of the sites investigated (100km south of the core research area), had almost identical compositions to other South Asian sites. This is significant as it implies an almost identical choice of raw materials and recipe in the manufacture of their crucibles. Since both Mawalgaha and Gattihosahalli both have relatively late dates (Anantharamu *et al* 1999; Juleff 1998; Wayman and Juleff 1999), it suggests that the production at site PM75 may also be of a later date.

The internal glassy slags were also compared to the main production sites in Central Asia (Merv, Pap and Akhsiket) but, due to their variability in composition, few trends were noticeable and significant composition overlaps with Central Asian sites were seen. The exception is in the TiO_2 and MnO content, which has been attributed to the addition of manganese oxide in the Central Asian process and the use of iron smelted from TiO_2 rich ores in Telangana. It was also noticed that the glassy slag composition was on the whole more comparable to those analysed from Merv. The Telangana glassy slag compositions were not different enough to other known sites to identify potential differences in crucible production methods, i.e. carburisation or co-fusion.

The seemingly infinite possibilities and variations of potential ingredients used to manufacture crucible steel, as well as conflicting historical accounts, makes it hard to pin-point the exact processes employed at these sites. However, the scientific results provided in this study suggests that crucible steel production in Telangana was well established and standardised, with similar (if not identical) materials and recipes used in the manufacture of all crucibles. The undeniable compositional similarities to other South Asian sites also points to strong socio-economic contacts throughout the whole region.

9 Conclusions

Archaeological research into crucible steel is a relatively recent discipline, with the first publications on sites and their remains appearing in the 1980-90's (Bronson 1986; Craddock 1998; Feuerbach *et al* 1997; Juleff 1990; 1998; Lowe 1989a; 1989b; 1995; Merkel *et al* 1995; Srinivasan 1994). Since then, a number of sites have been reported on; concentrated within two major geographical regions – Central Asia and South Asia. The nature of the evidence and a critical review of previous work has been discussed in chapter 2. As a whole though, crucible steel has too often been studied as a standalone technology, in isolation from other, wider regional patterns of ferrous metallurgy. Crucible steel being a refining process of iron has a symbiotic relationship with the smelting technologies that produced the raw material for refining. Therefore, by studying crucible steel manufacture within the wider context of iron production, a greater understanding of its techno-cultural role will be gained. This was the primary aim of this study in the region of Northern Telangana, South India.

Historical sources and recent archaeological field surveys have shown that Northern Telangana has a rich and diverse metallurgical past, including the manufacture of the famed crucible steel generally known as wootz. Despite this, little archaeometallurgical work has been conducted in the region to elucidate the nature, scale and diversity of the metallurgical technologies that underpinned the production of wootz. Lowe (1995) and Jaikishan (2009) are the only investigators to have tackled to some extent the recording of past metallurgical production in Northern Telangana. Their work demonstrated that the remains of iron smelting and crucible steel production were abundant and widespread. However, Lowe's research was never fully published and Jaikishan's work only provided a place-name catalogue of sites without detailed locational information, site descriptions or assessment of the waste materials observed. Indeed no previous research has tackled the detailed macro-morphological analysis of the archaeometallurgical debris from Telangana. There have been published crucible fabric analyses by Lowe (1989a; 1989b; Lowe *et al* 1991) and Balasubramaniam *et al* (2007) but even these focused primarily on one site – the village of Konasamudram. Thus a large gap remained in our understanding of how crucible steel was produced, the nature of its relationship with associated smelting technologies, and its place in the cultural landscape of Telangana.

Nonetheless, Lowe's and Jaikishan's work created both a foundation and an inspiration on which further work could be built. This was the aim of the Pioneering Metallurgy Project which instigated a reconnaissance field survey in 2010. Its objective was to address some of the gaps by identifying and recording as many metallurgical sites as possible within the Northern Telangana administrative districts of Karimnagar, Warangal, Nizamabad and Adilabad. The survey data and the large assemblage of technological material collected during the fieldwork became the focus of this current study.

The objective was to assess the field survey data combined with the detailed macro-morphological analysis of the collected technological waste assemblage. Sites of interest were recorded as 'locations' during the survey and the first step was to organise this 'locational' data into a coherent Microsoft Access database. The entire assemblage was then recorded in India, allowing the grouping of the material into types and sub-types based on shared morphological attributes. Location data and material typology were compared to resolve the final set of 'sites' which were then grouped into site types based on the nature of the evidence present. The focus of the study was on the metallurgical sites which were sub-divided again based on the dominant technological waste, resulting in smelting, smelting/crucible and crucible/smelting sites. During this process, patterns and trends in the data were continually assessed to inform on the scale and diversity of past metallurgical activities.

Research on this scale is not often attempted in the field of archaeometallurgical studies, partly due to the limitations imposed by the nature of a reconnaissance survey and the surface collection of materials. Namely, incomplete assemblages, poor preservation of materials and lack of stratigraphic context. These have been discussed in detail in the study and will be reassessed later in this chapter. It is important to note that the author was aware of such limitations from the outset and aimed to mitigate them by the in-depth recording of the assemblage and by integrating the observations with the field survey data. This not only allowed the identification of metallurgical activities but also helped to contextualise them within the wider environmental and cultural landscape.

Technological groups were identified by assessing material occurrence and co-occurrence on sites. A statistical method was attempted to achieve this but the nature of the data collection, which was mostly qualitative, prevented the efficacy of such an approach. Material co-occurrence and technological resolution was instead assessed manually as set out in chapter 4.2.3. This method was time consuming but more effective in identifying technological process types and variations. The familiarity gained with the material during the detailed recording process was a strength which mitigated some of the limitations of the dataset. It is important to recognise that this familiarity brought an element of subjectivity but that the systematic and in-depth nature of the recording procedure made it a strongly informed subjectivity. As a whole, the study was successful in identifying the scale and diversity of metallurgical production in Northern Telangana, and despite the limitations, the author is confident that the majority of the information was extracted out of the available dataset.

This chapter will start by discussing the most important findings in relation to the original aims and conclude by assessing the value of the study within the wider context of crucible steel production in Asia.

9.1 The Landscape of Metallurgy

An area which has received too little attention in previous studies is the setting of metallurgical activities within cultural and environmental landscapes. The 2010 survey addressed this by recording a range of historical features, whether apparently associated with metallurgy or not. This included settlements, temples and forts as well as geological features which could have been potential sources of iron ore (chapter 3 and 5). Although the recording of cultural features was not comprehensive, it was extensive and a representative characterisation of the landscape, and provided the context for the technologies under study. In brief, the region is now dominated by agricultural production, giving rise to a network pattern of villages and small regional towns, interspersed with protected tracts of forest and unproductive ranges of low hills. The same pattern is true of the past, albeit with less intensive agricultural production. The settlement pattern seen now is largely unchanged although while now irrigation is more centrally administered, in the past villages had their own manmade reservoirs (tanks) and were self-sustaining. Agriculture and village life are consumers of iron and also a source of manpower, thus a local demand and supply for iron was undoubtedly present.

The region also has an abundance of natural resources required for the maintenance of flourishing iron production activities. Iron ore is found in the banded magnetite-granite/quartzite outcrops or low hillocks which dominate the landscape. Good quality ores could have been picked from the surface, dug from the hillocks in shallow pits or even collected as a fine magnetite sand from small rivers and streams. Clays for furnace structures are plentiful in the region and fuel in the form of wood would have been readily available from the large expanses of dense forest. Although the acquisition of natural resources have not been investigated fully in this study, it seems reasonable to suggest that they were sourced readily and easily locally. Future analyses of iron ores and local clays in relation to the waste slags and refractory material recovered from metallurgical sites may reveal more on the provenance of the ingredients used in the production of iron and steel.

A total of 101 metallurgical sites were identified. These were found in varied location settings, within or on the edges of settlements, in surrounding agricultural fields or bare scrubland, to more isolated locations within forests. A common pattern amongst the majority of sites recorded was the high level of disturbance. Most sites located in village and agricultural settings had been partially removed or completely levelled in very recent years (indeed, in some cases as the survey was being conducted) to make way for agricultural or settlement expansion. In contrast, sites in areas with less intensive human activity, such as forests or unused land, showed much less disturbance, with the remains surviving almost intact. Remains located close to roads were also often partly removed as slags continue to be used as road ballast. Hence, perhaps unsurprisingly, higher levels of disturbance were identified in areas or locations with more intensive land-use.

As a first step in this study the metallurgical sites were grouped into general site types (chapter 5) based on the dominant technological waste present. The first major finding was the unequivocal dominance of the record by iron smelting, with all metallurgical sites surveyed having evidence of smelting, including those on which crucible steel was manufactured. Although a hint of this came across in Lowe's and Jaikishan's work, it was not specifically stressed, with smelting activities often overshadowed by discussion on the less numerous but more prestigious crucible steel manufacturing sites. This is interesting for several reasons. It demonstrates that crucible steel was not a standalone technology but part of a larger ferrous metallurgy repertoire. The presence of smelting on the same sites as crucible steel and the fact that residues of both technologies were mixed indicates that they were contemporary and operating side by side. This suggests that the feedstock of crucible steel (iron or steel) was probably produced on site or nearby, further reinforcing the idea that crucible steel production cannot be studied in isolation from the wider metallurgy record.

The recording of site setting during fieldwork proved to be valuable in assessing technological trends and their preferential occurrence within particular landscape or land-use contexts. It was shown (chapter 5) that iron smelting activities were located in much more varied settings, whereas crucible steel manufacture had a greater tendency to be situated within or close to settlements. It is proposed in this study that crucible steel production was more centralised, particularly the larger sites which are almost entirely found within or on the edges of villages. It is probable that a larger workforce was required and that the industry was subject to greater economic and administrative control, easier to manage within or close to larger settlements. It is also likely that villages provided better contact routes, facilitating the dynamic trade in crucible steel that is reflected in historical records (Tavernier 1679; Voysey 1832).

9.2 Identifying Technology and Technological Variation

One of the objectives of this study was to assess the scale and diversity of the metallurgical technologies in operation. To achieve this, the large assemblage of waste material collected during field survey was subjected to detailed macro-morphological analysis. The assemblage proved to be complex with a total of 56 material sub-types identified, each with their own morphological variations (chapter 6 and appendix C). The majority of the assemblage comprised tap slags, furnace slags and furnace wall fragments associated with iron smelting. Crucible remains and associated materials were found to be minor components, occurring on only 22% of the metallurgical sites recorded. The overwhelming dominance of iron smelting waste supports the assertion that smelting was the dominant technology operating in the region.

Material associations were then investigated by assessing which types and sub-types preferentially occurred together on sites. The aim was to identify more specific technological variations within the assemblage beyond the broad iron smelting and crucible steel groupings. This has not been attempted before in Northern Telangana or for that matter elsewhere in India, at least not on such a scale. Both Lowe and Jaikishan hinted at possible technological variation but neither defined this variation in detail. Jaikishan (2009) makes note that the residues on some sites were different but limited discussion is given and the waste materials themselves were not described. Lowe (1995) is more explicit in her interpretation, stating that there were two iron smelting variations based on the apparent ore type smelted. She noticed a difference in technological waste from sites that where probably sourcing their ores either from lateritic or magnetite deposits. However, once again limited discussion is provided and only initial interpretations presented, without an assessment of the residues or detailed description of the nature of the variation. Hence, the macro-morphological analysis of the material in this study was particularly important to provide a clear assessment of technological complexity.

Nine iron smelting and three crucible steel production groups were identified, based on the morphology of the material and their co-occurrence. The iron smelting technological groups were all consistent with the solid state reduction of iron oxides, analogous with the western 'bloomery' model (Pleiner 2000; Tylecote 1962; 1992). The main sources of variation were seen in furnace construction, tuyere shape and size, as well as the morphology of the slag. All smelting appears to have occurred in small shaft-type furnaces, varying in diameter from 200-600mm and the presence of tap slag on all sites suggests that the technologies were all slag tapping. The co-occurrence of different technological groups on some sites also suggests a progression or development of technological processes at site-level. Despite the degree of variation, one technology was dominant in the core research area suggesting that at one point in the past iron smelting was relatively standardised.

No obvious evidence for cast iron production or other smelting variants was identified. However, it must be briefly noted here that, due to the lack of archaeological evidence for cast iron production in India (chapter 2.2.3), we have no knowledge as to what kind of remains might be produced from such activities in the Indian context. Therefore, it is important to clarify that there is no evidence for cast iron production fitting with early European models of manufacture (Cleere and Crossley 1995; Craddock 1995; Tylecote 1987; Rostoker and Bronson 1990). This will be discussed in more detail later.

The three crucible steel technological groups identified also displayed interesting trends. The characteristics which defined these three groups were crucible shape and size. Groups 1 and 3 displayed a larger size range than group 2 crucibles, while the shape of the lids and bases also varied. The poor preservation of furnace walls on most sites limits comparative interpretation of the nature of the operating procedures. However, the better preserved remains suggest the use of coil built furnaces made of a coarse quartz-tempered clay with a diameter around 400-500+mm. The presence of a shaped stone furnace base on one site also suggests that at least some were built on stone platforms. Apart from differences in crucible morphology, their construction and associated waste were very similar across all sites and all groups. This included the presence of green glassy slags on all sites suggesting that a similar process was in operation. The crucible fabrics and their components also seem identical. All have black, rice husk tempered main body fabrics with a coarse quartz-tempered lid and exterior coating as well as black glassy fins on their interior surfaces. The only variation was the presence of an unidentified material (G3) only found on crucible group 3 sites.

Although technological groups and variants were identified, in-depth characterisation of the furnace structures and operating procedures is limited by the original fieldwork and surface sampling methods. The nature of a reconnaissance survey is to cover as much of the geographical area as possible to attain a wide picture of the technologies once in operation. This meant that sites were recorded in brief and the information documented selective, targeted for inter-site comparisons. The large team involved in the survey also created some degree of inconsistency in site records and sampling. This is the inevitable consequence of reconnaissance survey and more detailed follow up survey would be needed to bring certainty to the data.

Another limitation is the sampling methods. Without permission to excavate, all the materials were collected from the surface. Although this is a fast and relatively efficient way of recording materials present on sites and was conducted to be as representative as possible, it provides little archaeological and stratigraphic context. An unavoidable consequence of surface collection is that technological waste was often mixed, making it difficult to associate materials to specific technology type or group variants. Without stratigraphic context, assessing the development of technology at site-level was impossible. Care was taken to collect a good representation of all the material observed during the survey but it is also important to consider that since the majority of the material present on sites were part of heaped deposits, surface collection could not guarantee that all technologies, or variations, were represented. The fact that most sites were disturbed and the material fragmentary also hindered understanding and identification of technological specifics such as size and shape of the furnaces, and operating procedures.

Future work should include targeted excavations to identify the specifics of these technologies as well as the microstructural and compositional analysis of some of the waste material. Due to time constraints the large sample of smelting debris was not scientifically analysed. Doing so would undoubtedly reveal more information on the nature and operating parameters of the smelting technologies. This is particularly relevant for smelting technology group 7 which stood out from the rest, displaying residues not identified elsewhere (chapter 7.1.7). The unusual morphology of the waste prevented its identification but scientific analyses of the slags could help identify what was being produced.

It is also important to address the observations made by Lowe (1995) who suggested that smelting technology differed depending on the type of ore smelted. This was not possible to determine within the scope of this study. Lowe’s research focused on Nizamabad district, west of the main research area here. The geology in Nizamabad is more varied, including the presence of the Deccan Trap where lateritic ores are found. All sites surveyed in this study were located on banded-magnetite geology with possible ores sources within close range. The majority of the ore collected from sites was also magnetite and there is nothing to suggest an alternative source of iron ore. This of course cannot be determined through macro-morphological analysis alone but future compositional analyses of the remains would help ascertain what types of ore were smelted, particularly if a good selection of local ore types are also analysed for comparison. Therefore, it was not possible to verify Lowe’s suggestions but there is scope for future research to assess process variation based on ore type.

Despite the limitations imposed by the nature of a reconnaissance survey and surface collection of waste residues, the study identified important new evidence. The most notable of which was variation in smelting and crucible steel technology suggesting that the metallurgical technologies once in operation in Northern Telangana were complex. This is particularly important for crucible steel manufacture. The tendency of previous research to concentrate on the famous site of Konasamudram has meant that crucible steel is taken out of context from other ferrous production in the surrounding area. Although other crucible steel production sites had been identified by Lowe (1995) and Jaikishan (2009), no assessment and comparison of the waste had been conducted. The identification of crucible morphology variations indicates that there was localised variation in crucible steel manufacture and that the technology was perhaps not so special or unique but part of the repertoire of iron smelters.

9.3 Spatial and Temporal Distribution of Technology

Another aim of the study was to examine the spatial and temporal distribution of metallurgical technologies. The assessment of spatial distribution showed that technologies varied geographically (chapter 7). Two main smelting loci were observed (A and B – Figure 7.20). The largest locus (A) comprising the majority of surveyed sites was situated in the north-western part of Karimnagar district and dominated by smelting groups 1 and 2. The second locus (B) was much smaller, comprising a few sites concentrated within a 3.5km radius in the central part of Karimnagar district. These sites encompassed the entirety of the evidence for smelting groups 3, 4, 6 and 7, which were not identified anywhere else in the region. In addition, the most westerly and southerly sites, on the edges of the survey area, showed variation in technology (smelting groups 8 and 9). A similar pattern was observed for the crucible technologies, whereby all three groups were geographically distinct (Figure 7.22). Crucible technology group 1 was present in the most western part of the survey area, on the boundary between Karimnagar and Nizamabad district. Crucible group 2 dominated the north-western part of Karimnagar district, while crucible group 3 comprised the most southerly sites surveyed, in southern Karimnagar and Northern Warangal district. This demonstrates a pattern of regional variation.

At a more local level, the settings of particular technologies also revealed trends. Some smelting and crucible steel technological groups appeared to preferentially occur in and around settlements, while others were situated in more rural environs. For example, smelting groups 2, 4, 6 and 7 were all located outside villages, in agricultural land, unused land or forests, while smelting group 3 sites were all within or on the edge of villages. Of particular interest was smelting group 1 which was more widespread and present in varied settings. This is consistent with a development of standardisation of technology, whereby over time varying smelting practices become optimised and a dominant technological process emerges.

The crucible steel technologies displayed a similar trend. Crucible groups 1 and 3 sites were all located within or on the edge of settlements while crucible group 2 sites occurred in more varied settings, with approximately half situated within or close to settlements and the other half within agricultural land. It was also observed that crucible groups 1 and 3 were for the most part larger and more specialised in crucible steel production, with the majority of the remains comprising crucible fragments and associated materials. In contrast, crucible group 2 sites were dominated by smelting remains, with residues associated with crucible steel being less prominent. It has been proposed in this study that crucible groups 1 and 3 sites were more centralised and specialised, producing crucible steel on a larger scale intended for trade. On the other hand, crucible group 2 sites were smaller enterprises, producing a smaller quantity of crucible steel perhaps intended for a local market. The smaller size of type 2 crucibles would have produced smaller ingots more suited for everyday cutting tools, whereas the larger type 1 and 3 crucibles may have favoured the weaponry market where more material was required for the manufacture of swords. Voysey's (1832) account of crucible steel manufacture at Konasamudram (a crucible group 1 site) adds credence to this argument as he implies that the majority of the steel produced went to Persia.

However, possible causes for spatial and setting variation in technology groups are numerous. The most likely are that different groups of people with their own personalised traditions were responsible for the technological variants identified. This is particularly convincing when considering the preferential location settings of some technology groups. Perhaps, parts of the survey area were under different administrative or economic control, each with their own smelting or crucible steel manufacturing preferences. Another possibility is that different end products were being manufactured or similar products intended for different uses. Smelting iron intended for agricultural tools may have involved a different process than iron made for weapons or blades. Finally, the variation could also be temporal and reflect a development of metallurgical expertise and practice. Explaining the reasons for this technological variation was not possible within the scope of this study but suggested at. In order to gain a better understanding of technological variation, research into the past socio-economic aspects of the region needs to be conducted. Sites and technological types also need to be dated to offer a chronological dimension, and the residues need to be analysed scientifically to identify variation in the end products manufactured. The socio-economic environment of the region directly relating to metallurgical production is the subject of current research by Neogi (forthcoming). His findings may enlighten certain aspects of iron and crucible steel manufacturing variation and trends.

It is important to acknowledge that interpretation here is limited by the lack of temporal context. Although assessing temporal variation in technology was part of the original aims of this study, the absence of datable material and time-constraints prevented chronological resolution. Pottery was often found with or near the metallurgical activities but there is no existing typology of local pottery wares. In addition, the nature of the surface collection methodology means that there is no stratigraphic context, making it impossible to identify chronological evolution or development of technology at site level. The only datable references to smelting and crucible steel production in the region are the accounts of Havart and Voysey (Havart 1693; Voysey 1832). This places crucible steel manufacture in the late 17th century and beginning of the 19th century but neither mention the longevity of the activities or other production sites in the region. Nevertheless, due to the extent of the survey area and the abundance of different waste deposits observed at many of these sites, it is likely that there is evidence for temporal variation. Another consideration is that, since iron smelting shows multiple minor variations and crucible steel shows very little, smelting might have a greater temporal span than crucible steel production. In any case, future work should include the scientific dating of the materials collected and targeted excavations to gain some resolution in technological chronology.

It is also worth considering that the survey was not exhaustive. Jaikishan (2009) identified over 400 metallurgical sites during his survey, suggesting that the data presented here is only scratching the surface of the true scale of metallurgical production in Northern Telangana. There is scope for future work to expand the survey area to assess the fuller extent of technological variation.

9.4 The Relationship between Smelting and Crucible Steel

Assessing the inter-relationship between smelting and crucible steel technologies was an aim of the research. This is particularly important for identifying the provenance of the crucible steel feedstock. On the whole, studies in the discipline have in general failed to adequately demonstrate the sources of iron production associated with crucible steel. The focus of previous research has been on identifying crucible steel manufacturing processes through the analysis of the crucibles themselves (Balasubramaniam *et al* 2007; Lowe 1989a; 1989b; Lowe *et al* 1991; Rao *et al* 1970; Srinivasan 1994; 1997; 2007). Lowe (1995) was perhaps the first to attempt to connect local smelting activities with crucible steel production in Telangana. Using Voysey's (1832) account of the co-fusion process at Konasamudram, she suggests that both types of iron described as the crucible charge came from the local smelting of two different types of ore – lateritic ore and magnetite. However, this suggestion is not supported with substantial evidence, and as discussed earlier, Lowe's initial interpretations could not be verified here since the majority of the sites surveyed fall within a geographical area dominated by magnetite deposits only.

The best evaluation of technological connections that could be made within the scope of this research was assessing the nature of smelting on or in the vicinity of crucible steel manufacturing sites (chapter 7.4.3). As with other findings, interpretation is limited by the absence of dating, particularly in ascertaining whether smelting and crucible steel technologies were contemporary. However, the presence of smelting on all crucible sites and the fact that material from both processes were mixed suggests that the activities were operational within the same time-scale. It has been demonstrated that smelting activities on crucible steel sites were no different to those operating on smelting only sites. Despite some variations in smelting on different crucible site types, the activities appear to be identical to the dominant technology present in their respective geographical areas. This suggests that crucible steel production was very much embedded within the larger metallurgical tradition of Northern Telangana and that the feedstock was produced locally, if not on site itself. As suggested by Lowe (1995), crucible steel probably represented the intensification of the pre-existing iron processing industry.

It is also important to address the question of a co-fusion process and thereby the manufacture of cast iron. Voysey was explicit in his description of two different types of iron forming the crucible charge at Konasamudram, both of which were attained from villages nearby. These have generally been interpreted as wrought iron and cast iron, melted in the crucible to produce a steel of intermediate carbon-content (chapter 2.2.3). However, as highlighted by Craddock (2007) there is no archaeological evidence supporting the manufacture of indigenous cast iron, not just in Telangana but in the whole of India. This may be due to the general lack of excavation of iron smelting sites in India but even the survey conducted in Telangana and the macro-morphological analysis of the residues did not unearth any obvious signs of cast iron production. If the co-fusion process was adopted on all crucible steel sites identified, then one would expect cast iron to have been in demand and production sites numerous.

The fact that no cast iron production sites were identified suggests several possibilities. The first is the consideration that the co-fusion process was not used in Telangana. However, Voysey's account is very convincing in the description of the process and in the properties of the metals employed (chapter 2.2.3). Therefore another possibility is likely. Historical sources mention the production of cast iron in India as a by-product of the bloomery process (Holland 1892) suggesting that its production was known to Indian smelters. It also raises the issue that its production might not be immediately identifiable in the archaeological record, with residues identical to bloomery smelting operations. Therefore, it is possible that some of the smelting variants identified in this study produced cast iron but the remains may not be distinguishable from other smelting activities. Future work should attempt to address this through the analysis of some of the slags, which has the potential to reveal more aspects of the smelting processes than macro-morphology alone. The last consideration, of course, is that cast iron production did not occur in the survey area but was brought in from further afield. Lowe's suggestion that cast iron was produced from lateritic ores may be significant in this regard. Iron oxide rich laterite is found within the Deccan Trap which is located further west of the survey area, in Nizamabad district. It is possible that production of cast iron concentrated in that area. The indigenous production of cast iron is certainly a key theme in the evolution of ferrous metallurgy in India and targeted work needs to be conducted to identify sources of production.

9.5 The Crucible Steel Process

A major theme in crucible steel research has been the identification of the manufacturing process. Two main production methods have been proposed, the carburisation of wrought iron through the introduction of organic matter in the crucible charge, and the co-fusion of wrought iron and cast iron (chapter 2.2). Based on Voysey's (1832) account of production at Konasamudram, co-fusion has been widely accepted as the manufacturing method in Telangana. However, Havart's (1693) account of crucible steel production in this same region, over a century before Voysey, describes a different process, wherein the crucible charge consisted of only iron. In addition, an interview conducted by Jaikishan (2009; 2013) of a local smith from Konapur(am) described a carburisation process where wood and leaves were placed in the crucible (chapter 2.3.2). Konapur is a known crucible steel production site and was part of this study (PM60, PM61, PM62, PM63, PM64 and PM65). It is located c.10km east of Konasamudram and similar crucible group 1 remains were found at both sites. Combined with a lack of evidence for cast iron production there is now a case for challenging the co-fusion process in Telangana.

The scientific analysis of the internal glassy slags was hoped to generate discussion and provide clues as to the manufacturing process but the complete absence of comparative analyses from other sites in South Asia where carburisation has been claimed prevented comparison and identification of process. The morphology of the crucibles also did not provide many clues. There were no obvious signs that favoured either carburisation or co-fusion. The only exception are a few crucible lid fragments from one site where faint charcoal or wood impressions were identifiable on the interior surfaces. However, these were not common and could have been accidental in the preparation of the crucibles. Nevertheless, they could also suggest that organic matter was introduced in the crucibles as part of a carburisation process, but equally, the lack of organic impression on the majority of crucibles could also favour a co-fusion process.

The analysis of the internal glassy slags provides the best chance of identifying manufacturing processes and methods. However, the varying accounts of production in historical sources and the seemingly infinite variation of possible ingredients often prevents the deconvolution of crucible steel processes. This has been a problem not just in Telangana but in all crucible steel manufacturing areas. It is clearly seen in some of the analyses of Central Asian crucibles such as at Merv, where process interpretations have undergone several reassessments with no satisfactory conclusions reached (Feuerbach 2002; Feuerbach *et al* 1997; Merkel 2013). Although some attempts have been made (Merkel 2013) to test hypotheses by experimentation, the discipline would greatly benefit from additional investigations of various recipes as described in historical accounts. This could prove particularly valuable in the context of Telangana and South Asia where the two main production methods suggested in historical accounts are relatively consistent across the board, with little variation (chapter 2.2). A good start may be experimenting with Voysey's co-fusion recipe and carburisation as described by the smith interviewed by Jaikishan. The resulting waste could then be compared to the archaeological evidence to help resolve the co-fusion/carburisation conundrum.

The identification of different crucible forms is perhaps more significant and suggests that production varied across the region. Variation in crucible form was supported by the analyses of the lids and coarse exterior coatings which differed in composition between type 1 and type 2 crucibles. Taking into account the difference in location settings and site specialisation of each crucible group, it seems more probable that this variation was due to production by different groups of people in different time periods, than a difference of process operations or end product. Indeed, the crucibles were otherwise very similar. They all comprised the same fabric elements and the morphology of the internal glassy slag was identical. The main body fabrics of all three crucible types were undistinguishable microstructurally and compositionally. The chemical composition of the glassy slags were more variable but there were no trends pointing to differences in process or crucible charge. Therefore, it is possible to say that there was localised variation in form and fabric composition but that it does not transcend the overall similarity in construction and operating process. On the whole, all crucible steel types identified belong to the same technological tradition.

9.6 Wider Context

It is important to place the findings within the wider context of crucible steel production, particularly in relation to other sources of evidence from Central and South Asia. Previous work in both regions was discussed in detail in chapter 2. It is evident that there is a strong bias in both the analysis of crucible remains and dating evidence for Central Asia, with materials from South Asia lacking the same in-depth assessments and dating. Although this study cannot contribute precise dates to the discussion, the thorough investigation of crucible morphology and composition has created several interesting points of discussion.

Feuerbach (2007) proposed that the crucible steel process in Telangana was developed in Central Asia and that the Persians then influenced Indian production methods and techniques. She bases this interpretation on two aspects. The first relates to the production of crucible steel by co-fusion in Telangana as described by Voysey and the description of similar processes by Islamic writers and Massalaski's account in Central Asia (chapter 2.2.1). The second relates to crucible morphology and fabric composition. She suggests that the Telangana crucible form and the composition of the clay matrix as analysed by Lowe *et al* (1991) is more closely related to Central Asian crucibles than other South Asian examples. However, the analyses conducted in this study contradicts Feuerbach's (2007) interpretations.

The first consideration is that, to date, there is still no archaeological evidence for the co-fusion method, not only in Telangana but also in Central Asia. Indeed, it has been demonstrated that varying accounts of production have challenged the long held notion that co-fusion was the only operating process in Telangana. In addition, the comparison of internal crucible slag compositions from Telangana and sites in Central Asia (chapter 8.3) was not sufficiently conclusive to validate a clear difference in steel manufacturing process, even though all Central Asian production sites have been claimed to employ the carburisation method. The second consideration is that the comparison of crucible morphology (chapter 2) and fabric composition (chapter 8.3) has shown that crucible steel manufacture in Telangana was more closely related to other processes in South Asia than those in Central Asia. In fact, the almost identical fabric compositions and internal slag morphology suggests a distinct South Asian tradition of crucible steel manufacture, pointing to strong socio-economic ties across the region. It may also be possible to go further and suggest that the identification of other crucible forms in Telangana, particularly crucible type 2 which are very similar to examples in both Tamil Nadu and Sri Lanka, indicates that there was a gradual and perhaps continuous development of technology across the region.

However, it is important to recognise the limitations of such a hypothesis based on the evidence that is currently available. The greatest of which is dating. Very few of the South Asian sites have been dated. At the moment, the most concrete dating evidence comes from Sri Lanka, where two sites identified by Juleff (1998) are dated to the 6/7th century AD and 16-20th century AD. The South Indian sites on the other hand are only dateable through historical accounts of production, the earliest of which was in the 17th century AD. Despite the similarities in crucibles, this leaves a huge gap in production evidence of around 1000 years. It is possible that some of the other sites identified in India and in this study bridge this gap, but it is crucial that future work prioritizes dating to help clarify the chronology of development. Another limitation is the absence of crucible internal slag analyses for any of the South Asian sites. Comparison of these residues would provide the best chance in identifying variations or similarities in crucible steel manufacture process across the region, in turn helping to elucidate possible connections between different areas of production and inform on its origins and development.

Research on past crucible steel production still has a long way to go before we fully understand how it was manufactured, where its origins are, how it spread and how it evolved both in space and time. One way to progress is by considering the evidence of its production within the wider context of other associated ferrous metallurgies. It is important to remember that crucible steel was a refining process, and cannot be studied in isolation from these underpinning technologies. This is where the research presented in this study is the most valuable. Despite the lack of dating and confirmation of manufacturing process, the assessment of the technological context of crucible steel manufacture in Telangana has revealed that it was more widespread than originally known. The presence of regional variation in crucible form and fabric composition suggests that various groups of people were involved, each with their own traditions or idiosyncratic practices. The similarity of smelting activities on crucible steel sites to those on smelting-only sites in the region indicates that it represented an intensification of the local iron processing industry. All evidence points to the notion that crucible steel was perhaps not so unique or specialised as the few isolated sites commonly referenced to in the literature suggests.

Indeed, recent and ongoing research in the state of Andhra Pradesh, which adjoins Telangana at its southern border, has revealed several other crucible steel production sites. The full assessment of the data is not complete but the morphology of the crucibles, while varying in form from those in Telangana, fit within the South Asian tradition (Gullapalli pers. comm., 2016). It is likely that as more surveys are conducted, particularly around previously identified sites (such as Ghattihosahalli in Karnataka), more evidences of production are discovered, confirming the pattern identified in Telangana.

9.7 Future Work

The aim of this study was to document the archaeometallurgical evidence in Northern Telangana, identifying the technologies employed and placing them within the wider context of local metallurgical traditions. In no way could such a study resolve all outstanding questions regarding the production of crucible steel and iron smelting. However, by identifying regional patterns of technology it did provide a sturdy foundation on which future work can be built upon. Possibilities for future work have already been discussed in relevant sections throughout this thesis but it is important to address some of the more immediate problems here in more depth, particularly the issue of dating and crucible steel process identification.

As acknowledged previously, dating was the biggest limitation of this study which was not able to provide a chronological framework for the technologies identified. Therefore future work should prioritise a dating strategy. Several ways of dating the sites and their technological residues are possible. One option is to date the ceramic material (crucibles, tuyeres or furnace walls) collected by luminescence – thermoluminescence (TL) or optically stimulated luminescence (OSL). However, since the materials were all surface finds, the dates would not reflect the full temporal span of the metallurgical activities present. There would be no way of knowing if the material represented earlier or later manufacturing site trends. This might be especially problematic for the larger sites where the metallurgical activities could have spanned several centuries.

A more reliable option for dating would be through excavation combined with C^{14} dating. Excavation would provide a stratigraphic context for the residues and allow for any potential progression in technology to be assessed at site level. The dating of these layers would also provide more accurate data relating to the lifespan of the metallurgical activities. C^{14} dating is ideal for dating metallurgical sites as charcoal fragments are commonly found in the waste heaps. It will therefore be essential to identify and collect this datable material during the excavations. If organic remains for C^{14} dating have for some reason not been preserved, then dating may be acquired or supported by another dating method such as TL or OSL.

Excavation should target a good selection of sites representative of the major technological groupings and location settings. Since many of the sites were heavily disturbed, comprising large surface scatters, it is important to select better preserved sites with *in situ* heaped remains which have the potential to provide better stratigraphic data. Table 9.1 shows recommended sites for each technological group which would be suitable for future excavation and dating strategies. Some of these sites have evidence for more than one technological group making them particularly valuable to elucidate further technological connections and identify developments or progressions of technology at site level. Sites PM46, PM79, PM80 and PM112 should be considered as they all have evidence for smelting group 1 (or 1.1/1?) and smelting group 2, the most common and widespread smelting technologies. It will also be important to investigate the temporal relationship between group A and group B sites (chapter 7.4.1) which differ considerably in materials used in furnace construction and probably also in furnace operation. Identifying whether or not these technologies were contemporary will reveal clues as to whether they were operated by different groups of people with their own idiosyncratic practices or whether they differ because they are temporally distant, representing developments in technology.

The same is true for the three crucible technological groups. Future work needs to resolve their dating in order to identify if they are contemporary, hence, possibly representing localised idiosyncratic practices, or if the practices were temporally distant, suggestive of an evolution or development of manufacture. To achieve this, the best preserved and most characteristic sites are proposed for future excavation and dating. Sites PM60, PM65 and PM106 for crucible group 1 as these represent the three core village sites (Konapur, Konasamudram and Ibrahimpatnam) where this technology was identified. Likewise, sites PM75 and PM103 are recommended for crucible group 3 as these represent the two village sites where this technology was observed (Parasurampalli and Gopalpur). Further investigation of sites PM18, PM54, PM88 and PM119 are also proposed for crucible group 2 sites as these have the best preserved *in situ* remains with additional evidence for smelting group 1 (or 1?).

Table 9.1 - List of recommended sites suitable for future excavations and dating strategies for each technological group.

Technological Group	Recommended sites (PM)
Smelting group 1	18; 40; 44; 45; 46; 47; 52; 54; 55; 56; 77; 82; 99; 100; 112; 118
Smelting group 1.1	46; 55; 73
Smelting group 2	46; 79; 80; 112
Smelting group 3	24; 26; 34
Smelting group 4	28
Smelting group 5	3
Smelting group 6	30
Smelting group 7	35
Smelting group 8	74
Smelting group 9	60
Crucible group 1	60; 65; 106
Crucible group 2	18; 54; 55(?); 88; 119
Crucible group 3	75; 103

Another key area that requires future work is the identification of the crucible steel process – carburisation or co-fusion. This has been discussed at length in this study and future work has been proposed, ranging from additional analyses of crucible fabrics and waste from other South Asian sites to provide comparison with those from Telangana, to potential experimentation of both processes as described in historical and ethnographic records followed by the analysis of the resulting waste (chapters 8.3.3 and 9.5). However, in the short term it may be possible to attain some resolution or at least gain further understanding through mass balance calculations as exemplified by Rehren and Papakhristu (2000).

Rehren and Papakhristu (2000, 58-64) successfully disproved the theory that iron ores were directly smelted to steel within the crucibles from Akhsiket (Uzbekistan), proposing instead a carburisation method of steel production. They did this by taking known crucible parameters such as volume and composition of the ingot and internal glassy slag waste, as well as the total volume of the crucibles, to work out the iron content of the charge and the amount of charcoal necessary to smelt the charge to steel. Assuming that the crucibles were charged before firing and that nothing was added during the process, they worked out that the total crucible volume was insufficient to hold enough ore and charcoal to reduce the iron oxide in the ore to produce an ingot the size of which is seen in the archaeological record. The limiting factors for charge constituents were therefore the total crucible volume and the known ingot, slag and free space volume.

Although it was not possible to undertake such calculations within the scope of this study, minimal additional work would be required to gain sufficient data for a first attempt. From the measurements taken of the crucibles it would be possible to estimate the total internal volume as well as that of the ingot and glassy slag. Since the Telangana crucibles do not have the same homogeneity in size as those from Akhsiket, calculations for several size ranges and for the three different crucible types would have to be made. If the same process was being used across all sites in the region it might be expected that despite differences in crucible size and form, the volume proportions of the crucibles are consistent across the board. Indeed, this might prove to be interesting in itself.

It is important to recognise that any attempt to propose process reconstructions using this method would inevitably be hypothetical 'best case' scenarios but it might be particularly useful to see if steel production was possible using carburisation or co-fusion in the Telangana context. For example, would the crucible volume be sufficient to hold enough carboniferous material and iron to carburise the latter into steel consistent with the ingot and slag volumes/compositions seen in the archaeological record. It is also worth mentioning that the analysis of the iron smelting slags from crucible production sites would also be useful to gain a greater understanding of the process. They would allow comparisons to be made with the crucible internal glassy slags. Combined with the known compositions of the crucible ceramic fabrics it may be possible to work out how much each constituent (smelting slag, crucible fabric and charge) contributed to slag formation within the crucibles.

This may also allow the identification of possible fluxes and/or other constituents of the original charge.

9.8 Conclusion

The tendency of previous research to study individual sites isolated from their wider technological context has led to an impression that they are unique, special or distinctive in some way. This has not been helped by the legends surrounding the production and use of crucible steel in the manufacture of swords and weapons, including the fabled Damascus swords. It is without question that the manufacture of crucible steel was a revolutionary step in the development of ferrous metallurgy. It provided for the first time, impurity-free high-carbon steel suitable for edged tools and weapons. However, as expressed by Bronson (1986), this technology probably produced a variety of different end products for a variety of different uses. This included everyday items such as household and agricultural tools (Jaikishan 2009; Jaikishan and Balasubramaniam 2007a). The survey and subsequent analysis of the waste materials associated with smelting and crucible steel in Telangana has identified a much more widespread production industry with varying degrees of site specialisation. This suggests that crucible steel was perhaps more common and less special than previously thought, less of a specialty product for a narrow elite but accessible to a larger section of the populace.

As a whole there is scope for further work in this field, none more so than placing these main manufacturing areas within a chronological framework of production. This would help in identifying the evolution of crucible steel, inform on its origins and allow for more interpretation of their link with dated sites in Central Asia and Sri Lanka. Too long has it been assumed that crucible steel originated in South India without the archaeological evidence to support such claims. The over-reliance on historical sources is also problematic and has yet to satisfactorily answer some of the more pressing questions associated with its manufacture, origins and spread.

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The Technological Context of Crucible Steel Production in Northern Telangana, India.

Volume 2 of 2

(Appendices)

Submitted by Brice Max Girbal,

to the University of Exeter

as a thesis for the degree of

Doctor of Philosophy in Archaeology,

January 2017.

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

(Signature) ………………………………………………………………………………

Table of Contents (Volume 2)

Appendix A – Pioneering Metallurgy Fieldwork Location and Site Records

Appendix A.1 – Fieldwork Location Records

This appendix presents the 'location' records collected during the Pioneering Metallurgy survey, including site group, site type, location setting type, preservation status, size, deposit depth and GPS coordinates as described in Chapter 4.

Location	General placename	Site No	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
24/01/10 1	Kotilingala	PM1	Historic	settlement	SE-BS	dis.	lg.	deep	18° 51' 34.6"	79° 11' 51.4"
24/01/10 2	Kotilingala	PM1	Historic	settlement	SE-BS	dis.	lg.	deep	18° 51' 36.0"	79° 11' 48.6"
24/01/10 3	Kotilingala	PM1	Historic	settlement	SE-A	dis.	lg.	deep	18° 51' 41.0"	79° 11' 42.3"
24/01/10 5	Kotilingala	PM1	Historic	settlement	SE-A	prim.	lg.	deep	18° 51' 37.6"	79° 11' 36.5"
24/01/10 6	Kotilingala	PM2	Historic	temple	SE	dis.	lg.	deep	18° 51' 45.4"	79° 11' 54.1"
25/01/10 1	Buggaram	PM3	Metallurgical	smelting - scatter	BS	dis/sec.	med.	med.	18° 52' 09.5"	79° 03' 32.9"
25/01/10 2	Buggaram	PM4	Historical	pottery scatter	BS	prim.	lg.	med.	18° 52' 00.5"	79° 03' 34.0"
25/01/10 3	Buggaram	PM4	Historical	pottery scatter	A	dis.	lg.	deep	18° 51' 59.53"	79° 03' 30.94"
25/01/10 4	Buggaram	PM5	Geological	quarry (modern)	BSH	prim.	lg.	deep	18° 52' 02.83"	79° 03' 23.4"
25/01/10 5	Buggaram	PM3	Metallurgical	ore processing?	BS	prim.	lg.	sh.	18° 52' 03.0"	79° 03' 33.1"
25/01/10 6	Buggaram	PM3	Metallurgical	smelting	B	prim.	lg.	deep	18° 52' 05.2"	79° 03' 33.5"
26/01/10 1	Sirikonda	PM6	Geological	ore deposit	BSH	prim.	lg.	deep	18° 51' 33.04"	79° 06' 26.7"
26/01/10 2	Sirikonda	PM6	Geological	ore deposit	BSH	prim.	lg.	deep	18° 51' 31.86"	79° 06' 20.09"
26/01/10 3	Sirikonda	PM6	Geological	ore deposit	BSH	prim.	lg.	deep	18° 51' 30.84"	79° 06' 15.86"
26/01/10 4	Sirikonda	PM6	Geological	quarry (modern)	BSH-SE	prim.	lg.	deep	18° 51' 22.12"	79° 06' 18.19"
26/01/10 6	Sirikonda	PM7	Metallurgical/Ethno	operational smithy	S	prim.	med.	med.	18° 51' 22.7"	79° 06' 30.6"
26/01/10 7	Sirikonda	PM8	Metallurgical	smelting	S	dis.	med.	med.	18° 51' 23.1"	79° 06' 28.4"
26/01/10 8	Sirikonda	PM9	Metallurgical	smelting/crucible	S	dis.	med.	deep	18° 51' 22.4"	79° 06' 31.3"

Location	General placename	Site No	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
28/01/10 1	Kalleda	PM10	Metallurgical	smelting	BS	dis.	med.	med.	18° 51' 35.2"	79° 00' 54.8"
28/01/10 2	Kalleda	PM11	Metallurgical	smelting	A	dis/sec?	med.	sh/med.	18° 51' 35.8"	79° 00' 58.6"
28/01/10 3	Kalleda	PM12	Geological	quarry	BSH	sec?	N/A	section	18° 51' 34.1"	79° 01' 9.01"
28/01/10 4	Yeshwantareopeta	PM13	Geological	quarry	BSH-SE	N/A	N/A	section	18° 50' 49.0"	79° 02' 27.1"
28/01/10 5	Shekalla	PM14	Metallurgical	smelting	S	Dis.	sm.	deep	18° 50' 21.4"	79° 04' 20.6"
28/01/10 6	Shekalla	PM15	Metallurgical/Ethno	operational smithy	S	N/A	N/A	N/A	18° 50' 31.3"	79° 04' 14.2"
28/01/10 7	Shekalla	PM16	Metallurgical/Ethno	operational smithy	S	N/A	N/A	N/A	18° 50' 28.1"	79° 04' 14.9"
28/01/10 8	Shekalla	PM17	Geological	mining pits	BSH	N/A	N/A	N/A	18° 50' 36.3"	79° 04' 40.8"
29/01/10 1	Chinna Nakkalapet	PM18	Metallurgical	smelting/crucible	A-SE	dis.	lg.	sh.	18° 58' 39.4''	79° 04' 21.0''
29/01/10 2	Chinna Nakkalapet	PM18	Metallurgical	smelting/crucible	A-SE	dis.	lg.	deep	18° 58' 40.7''	79° 04' 21.4''
29/01/10 3	Chinna Nakkalapet	PM18	Metallurgical	smelting/crucible	A-SE	prim.	lg.	deep	18° 58' 40.1''	79° 04' 21.1''
29/01/10 4	Chinna Nakkalapet	PM19	Metallurgical	smelting/crucible	A-SE	dis.	med.	sh.	18° 58' 36.9''	79° 04' 23.3''
29/01/10 5	Chinna Nakkalapet	PM20	Historic	settlement	A	prim.	med.	N/A	18° 58' 13.4''	79° 04' 32.9''
30/01/10 1	Narella	PM21	Metallurgical	smelting - sec	S	sec.	lg.	sh.	18° 55' 20.5"	79° 01' 58.5"
30/01/10 2	Narella	PM22	Metallurgical	smelting	S	dis.	lg.	sh.	18° 55' 23.4''	79° 01' 53.3''
30/01/10 3	Narella	PM23	Metallurgical/Ethno	operational smithy	BS-SE	N/A	N/A	N/A	18° 55' 32.0''	79° 01' 28.7''
01/02/10 1	Arnakonda	PM24	Metallurgical	smelting	SE-A	dis.	lg.	deep	18° 37' 07.0"	79° 09' 47.8"
01/02/10 2	Arnakonda	PM24	Metallurgical	smelting - scatter	SE-A	sec.	lg.	sh.	18° 37' 05.5"	79° 09' 47.0"
01/02/10 3	Arnakonda	PM26	Metallurgical	smelting	S	dis.	lg.	deep	18° 37' 03.8"	79° 09' 52.2"
01/02/10 4	Arnakonda	PM26	Metallurgical	smelting - scatter	S	sec.	lg.	sh.	18° 37' 03.7"	79° 09' 50.4"
01/02/10 5	Arnakonda	PM27	Metallurgical	smelting	S	dis/sec?	sm.	deep	18° 36' 48.3"	79° 09' 49.7"
01/02/10 6	Mallapur	PM28	Metallurgical	smelting	A	prim	lg.	deep	18° 38' 50.8"	79° 09' 39.6"
01/02/10 7	Mallapur	PM29	Geological	mining pits	A	dis.	lg.	N/A	18° 38' 44.8"	79° 09' 42.5"
01/02/10 8	Mallapur	PM30	Metallurgical	smelting	A	dis.	lg.	deep	18° 39' 49.2"	79° 09' 50.9"
01/02/10 9	Arnakonda	PM25	Historic	temple	SE-A	prim.	sm.	N/A	18° 37' 05.5"	79° 09' 47"
02/02/10 1	Abbapur	PM31	Metallurgical	smelting - scatter	A	dis.	lg.	sh.	18° 39' 49.0"	79° 11' 54.8"
02/02/10 2	Abbapur	PM32	Historic	settlement?	A	prim.	lg.	N/A	18° 39' 49.9"	79° 12' 00.7"

Location	General placename	Site No	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
02/02/10 3	Abbapur	PM33	Findspot	findspot	A	sec.	sm.	sh.	18° 39' 14.9"	79° 12' 25.9"
02/02/10 4	Kammarikhampet	PM34	Metallurgical	smelting - sec	S	sec.	lg.	sh.	18° 38' 07.3"	79° 11' 51.1"
02/02/10 5	Kammarikhampet	PM34	Metallurgical	smelting	S	dis.	med.	deep	18° 38' 07.9"	79° 11' 51.9"
02/02/10 6	Kammarikhampet	PM34	Metallurgical	smelting	SE-BS	dis.	med/lg.	deep	18° 38' 08.9"	79° 11' 53.0"
02/02/10 7	Kammarikhampet	PM34	Metallurgical	smelting (furnace)	SE-BS	prim.	sm.	med.	18° 38' 09.6"	79° 11' 53.2"
02/02/10 8	Mallapur	PM35	Metallurgical	smelting - scatter	A	sec.	lg.	sh.	18° 39' 37.7"	79° 09' 26.1"
02/02/10 9	Mallapur	PM36	Geological	ore deposit	BS-A	prim.	lg.	deep	18° 39' 44.7"	79° 09' 25.5"
03/02/10 16	Lachakkapet	PM37	Historic	fort	A	prim.	N/A	N/A	18° 52' 29.9"	78° 54' 39.2"
03/02/10 2	Lachakkapet	PM38	Metallurgical	smelting - sec	A	sec.	lg.	sh.	18° 52' 28.0"	78° 54' 41.2"
03/02/10 3	Lachakkapet	PM39	Metallurgical	smelting	A	dis.	lg.	deep	18° 52' 26.6"	78° 54' 47.0"
03/02/10 4	Lachakkapet	PM40	Metallurgical	smelting	A	dis.	lg.	deep	18° 52' 36.2"	78° 54' 59.4"
03/02/10 5	Lachakkapet	PM41	Historic	pottery scatter	A	sec.	lg.	sh.	18° 52' 38.02"	78° 55' 03.54"
03/02/10 6	Lachakkapet	PM42	Metallurgical	smelting	A	dis.	lg.	deep	18° 52' 43.2''	78° 55' 06.4"
03/02/10 7	Lachakkapet	PM40	Metallurgical	smelting	A	dis.	lg.	deep	18° 52' 35.7''	78° 55' 0.18"
03/02/10 8	Rangapeta	PM43	Metallurgical/Ethno	operational smithy	S	N/A	N/A	N/A	18° 53' 44.6''	78° 54' 30.5"
03/02/10 9	Rangapeta	PM44	Metallurgical	smelting	SE-A	dis.	lg.	deep	18° 53' 42.0''	78° 54' 29.3"
03/02/10 10	Rangapeta	PM44	Metallurgical	smelting	SE-BS	?	?	?	18° 53' 44.5''	78° 54' 29.0"
03/02/10 11	Raikal	PM45	Metallurgical	smelting	SE-BS	dis.	lg.	deep	18° 54' 40.8''	78° 48' 37.2"
03/02/10 12	Raikal	PM45	Metallurgical	smelting	SE-BS	dis.	lg.	deep	18° 54' 43.8''	78° 48' 40.5"
03/02/10 13	Ayodya/Uppumadugu	PM46	Metallurgical	smelting	A	dis.	lg.	deep	18° 53' 27.5''	78° 51' 38.9"
03/02/10 14	Ayodya/Uppumadugu	PM46	Metallurgical	smelting	A	dis.	ig.	deep	18° 53' 27.3''	78° 51' 40.7"
03/02/10 15	Ayodya/Uppumadugu	PM46	Metallurgical	smelting	A	dis.	lg.	deep	18° 53' 25.3''	78° 51' 45.8"
03/02/10 1	Lachakkapet	PM38	Metallurgical	smelting - scatter	A	sec.	lg	sh.	18° 52' 29.9"	78° 54' 39.2"
05/02/10 1	Rechapally	PM47	Metallurgical	smelting	A	dis.	lg.	deep	18° 56' 47.2''	78° 56' 06.6''
05/02/10 2	Rechapally	PM48	Metallurgical	smelting	A	dis.	lg.	deep	18° 56' 55.1''	78° 56' 07.0''
05/02/10 3	Rechapally	PM49	Metallurgical	smelting - scatter	S	dis.	lg.	sh.	18° 56' 10.4''	78° 55' 46.0''
05/02/10 4	Rechapally	PM49	Metallurgical	smelting	SE-A	dis.	lg.	deep	18° 56' 13.7''	78° 55' 43.1''

Location	General placename	Site No	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
05/02/10 5	Rechapally	PM50	Metallurgical	smelting - scatter	S	sec.	lg.	sh.	18° 55' 52.5''	78° 55' 49.0''
05/02/10 6	Konapur	PM51	Metallurgical	smelting	SE-A	dis.	med.	med.	18° 52' 24.0''	78° 55' 58.1''
05/02/10 7	Konapur	PM52	Metallurgical	smelting	A	prim.	lg.	deep	18° 52' 18.8''	78° 56' 03.0''
06/02/10 1	Kalleda	PM53	Historic	pottery scatter	A	sec.	sm/med.	sh.	18° 50' 36.4''	79° 00' 20.1''
06/02/10 2	Kalleda	PM54	Metallurgical	smelting/crucible	A	prim.	med.	deep	18° 50' 34.3''	79° 00' 11.6''
06/02/10 3	Kalleda	PM54	Metallurgical	smelting	A	dis.	med.	deep	18° 50' 37.2''	79° 00' 12.6''
06/02/10 4	Kalleda	PM54	Metallurgical	smelting - scatter	A	prim.	lg.	sh.	18° 50' 37.0''	79° 00' 13.3''
08/02/10 1	Nawabpet	PM55	Metallurgical	smelting/crucible	A	prim.	lg.	deep	19° 07' 21.1''	78° 49' 33.2''
08/02/10 2	Nawabpet	PM55	Metallurgical	smelting	A	prim.	lg.	deep	19° 07' 22.4''	78° 49' 34.7''
08/02/10 3	Nawabpet	PM55	Metallurgical	smelting - sec?	F-A	sec.	lg.	deep	19° 07' 22.7''	78° 49' 33.6''
08/02/10 4	Nawabpet	PM56	Metallurgical	smelting	F	prim.	lg.	deep	19° 08' 25.7''	78° 49' 04.7''
08/02/10 5	Nawabpet	PM56	Metallurgical	smelting	F	prim.	lg.	deep	19° 08' 28.0''	78° 49' 06.0''
08/02/10 6	Nawabpet	PM56	Metallurgical	smelting	F	prim.	lg.	deep	19° 08' 28.6''	78° 49' 06.0''
08/02/10 7	Nawabpet	PM56	Metallurgical	smelting	F	prim.	lg.	deep	19° 08' 29.1''	78° 49' 06.0''
08/02/10 8	Kalleda	PM57	Metallurgical	smelting	A	dis.	lg.	deep	19° 08' 04.2''	78° 52' 17.4''
08/02/10 9	Kalleda	PM58	Metallurgical	smelting/crucible	A	dis.	lg.	med.	19° 08' 09.4''	78° 52' 15.9''
08/02/10 10	Kalleda	PM58	Metallurgical	smelting	A	dis.	lg.	med.	19° 08' 10.0''	78° 52' 14.2''
08/02/10 11	Kalleda	PM59	Findspot	findspot	A	sec.	sm.	sh.	19° 08' 08.5''	78° 52' 16.6''
09/02/10 1	Konapur	PM60	Metallurgical	crucible/smelting	SE-A	prim.	lg.	deep	18° 43' 10.5''	78° 37' 06.4''
09/02/10 2	Konapur	PM60	Metallurgical	crucible/smelting	S	dis.	lg.	deep	18° 43' 11.1''	78° 37' 08.0''
09/02/10 3	Konapur	PM61	Metallurgical	smelting	SE-A	dis.	lg.	deep	18° 43' 16.4''	78° 37' 09.9''
09/02/10 4	Konapur	PM60	Metallurgical	smelting/crucible - sec	S	sec.	med.	med.	18° 43' 07.4''	78° 37' 6.07''
09/02/10 5	Konapur	PM62	Metallurgical	crucible/smelting	A	dis.	lg.	med.	18° 43' 07.1''	78° 36' 49.3''
09/02/10 6	Konapur	PM63	Metallurgical	smelting/crucible?	A	dis.	lg.	med.	18° 43' 09.4''	78° 36' 33.8''
09/02/10 7	Konapur	PM64	Metallurgical	smelting	A	dis.	lg.	med.	18° 43' 01.6''	78° 37' 42.3''
10/02/10 1	Konasamudram	PM65	Metallurgical	crucible/smelting	SE-BS	dis.	lg.	deep	18° 43' 48.5"	78° 31' 27.1"
10/02/10 2	Konasamudram	PM65	Metallurgical	crucible	SE-BS	dis.	med.	deep	18° 43' 49.1"	78° 31' 26.7"

Location	General placename	Site No	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
10/02/10 3	Konasamudram	PM66	Historic	structure	S	N/A	N/A	N/A	18° 43' 40.5"	78° 31' 25.0"
10/02/10 4	Konasamudram	PM67	Metallurgical	crucible/smelting	SE-A	dis.	lg.	med.	18° 43' 41.2"	78° 31' 28.4"
11/02/10 1	Nagaram	PM69	Metallurgical	smelting	S	dis.	sm.	med.	18° 55' 30.2"	79° 04' 22.8"
11/02/10 2	Nagaram	PM70	Metallurgical	smelting - scatter	A	dis.	?	sh.	18° 55' 11.6"	79° 04' 09.8"
11/02/10 3	Nagaram	PM70	Metallurgical	smelting (presumed)	A	?	?	?	18° 55' 12.8"	79° 04' 03.0"
11/02/10 4	Nagaram	PM71	Metallurgical/Ethno	operational smithy	S	N/A	N/A	N/A	18° 55' 35.2"	79° 04' 30.3"
11/02/10 5	Maddunur	PM72	Metallurgical	smelting	BSH	prim.	lg.	deep.	18° 52' 13.5"	79° 05' 55.1"
11/02/10 6	Maddunur	PM73	Metallurgical	smelting	BS-SE	dis.	med/lg.	deep.	18° 51' 49.1"	79° 06' 13.2"
12/02/10 1	Parasurampalli	PM74	Metallurgical	smelting	BS	dis.	lg.	deep	18° 21' 30.4"	79° 53' 28.6"
12/02/10 2	Parasurampalli	PM74	Metallurgical	smelting	BS	prim.	sm.	deep	18° 21' 30.6"	79° 53' 28.7"
12/02/10 3	Parasurampalli	PM75	Metallurgical	crucible/smelting	A	dis.	lg.	med.	18° 21' 23.1"	79° 53' 28.3"
12/02/10 4	Parasurampalli	PM75	Metallurgical	crucible/smelting	A	prim.	lg.	deep	18° 21' 25.0"	79° 53' 29.2"
12/02/10 5	Parasurampalli	PM75	Metallurgical	crucible/smelting	A	prim.	lg.	deep	18° 21' 25.1"	79° 53' 32.7"
12/02/10 6	Parasurampalli	PM74	Metallurgical	smelting	A	dis.	lg.	med/dp	18° 21' 32.9"	79° 53' 30.1"
12/02/10 7	Parasurampalli	PM74	Metallurgical	smelting	A-SE	prim.	lg.	deep	18° 21' 32.9"	79° 53' 25.5"
12/02/10 8	Parasurampalli	PM74	Metallurgical	smelting	A-SE	dis.	med.	med/dp	18° 21' 30.5"	79° 53' 23.6"
12/02/10 9	Parasurampalli	PM74	Metallurgical	smelting - scatter	A-SE	dis.	med.	sh.	18° 21' 27.5"	79° 53' 22.4"
12/02/10 10	Parasurampalli	PM74	Metallurgical	smelting - scatter	A	dis.	med.	sh.	18° 21' 24.0"	79° 53' 21.3"
13/02/10 1	Rangasagar	PM76	Metallurgical	smelting	A	dis.	med/lg.	sh/med?	19° 01' 32.3"	78° 55' 28.2"
13/02/10 2	Rangasagar	PM77	Metallurgical	smelting	A	dis.	med?	deep	19° 01' 40.5"	78° 55' 24.7"
13/02/10 3	Rangasagar	PM77	Metallurgical	smelting	A	dis.	med/lg?	deep.	19° 01' 40.8"	78° 55' 21.7"
13/02/10 4	Rangasagar	PM77	Metallurgical	smelting	A	dis.	med.	med.	19° 01' 40.5"	78° 55' 21.3"
13/02/10 5	Rangasagar	PM78	Historic	settlement	BS-A	N/A	N/A	N/A	19° 01' 40.1"	78° 55' 17.7"
13/02/10 6	Davanpally	PM79	Metallurgical	smelting	F	prim.	sm/med?	deep	19° 00' 40.6"	78° 52' 05.6"
13/02/10 7	Davanpally	PM79	Metallurgical	smelting	F	prim.	sm/med?	deep	19° 00' 40.9"	78° 52' 05.6"
13/02/10 8	Davanpally	PM79	Metallurgical	smelting	F	prim.	sm/med?	deep	19° 00' 41.2"	78° 52' 06.3"
13/02/10 9	Davanpally	PM79	Metallurgical	smelting	F	prim.	sm/med?	deep	19° 00' 41.2"	78° 52' 06.5"

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Location	General placename	Site No	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
13/02/10 10	Davanpally	PM79	Metallurgical	smelting	F	prim.	sm/med?	deep	19° 00' 41.5"	78° 52' 06.7"
13/02/10 11	Davanpally	PM79	Metallurgical	smelting	F	prim.	sm/med?	deep	19° 00' 41.9"	78° 52' 06.9"
13/02/10 12	Davanpally	PM79	Metallurgical	smelting	F	prim.	med?	deep	19° 00' 43.3"	78° 52' 07.4"
13/02/10 13	Davanpally	PM79	Metallurgical	smelting	F	prim.	med?	deep	19° 00' 43.3"	78° 52' 07.9"
13/02/10 14	Davanpally	PM79	Metallurgical	smelting	F	prim.	med?	deep	19° 00' 42.8"	78° 52' 08.4"
13/02/10 15	Davanpally	PM79	Metallurgical	smelting (furnace)	F	prim.	sm.	med.	19° 00' 40.8"	78° 52' 05.9"
15/02/10 1	Kairigudam	PM80	Metallurgical	smelting	F	prim.	med.	deep	18° 58' 39.6''	78° 54' 02.6''
15/02/10 2	Kairigudam	PM80	Metallurgical	smelting	F	prim.	lg.	deep	18° 58' 37.3''	78° 54' 02.8''
15/02/10 3	Kairigudam	PM80	Metallurgical	smelting	F	prim.	lg.	deep	18° 58' 39.0''	78° 54' 03.3''
15/02/10 4	Kairigudam	PM80	Metallurgical	smelting (furnace)	F	prim.	sm.	med.	18° 58' 38.1''	78° 54' 03.4''
15/02/10 5	Kairigudam	PM80	Metallurgical	smelting (furnace)	F	prim.	sm.	med.	18° 58' 38.3''	78° 54' 02.6''
15/02/10 6	Katkapur	PM81	Prehistoric/Met	stone tool scatter	A	dis.	lg.	sh.	18° 59' 50.7''	78° 53' 02.6"
16/02/10 1	Potharam	PM82	Metallurgical	smelting	SE-A	dis.	lg.	deep	18° 56' 54.8''	78° 59' 00.5"
16/02/10 2	Potharam	PM83	Metallurgical	smelting	A-SE	dis.	lg.	deep	18° 57' 06.7''	78° 58' 34.0"
16/02/10 3	Potharam	PM83	Metallurgical	smelting	A-SE	dis.	med.	med.	18° 57' 03.7''	78° 58' 31.8"
16/02/10 4	Potharam	PM84	Metallurgical	smelting/crucible - scatter	A-SE	dis.	lg.	sh.	18° 57' 13.1''	78° 58' 35.2"
16/02/10 5	Potharam	PM84	Metallurgical	smelting/crucible	A-SE	dis.	med.	deep	18° 57' 12.1''	78° 58' 34.2"
16/02/10 6	Potharam	PM85	Metallurgical	smelting - scatter	A	dis.	lg.	sh.	18° 56' 10.2''	79° 00' 05.8"
16/02/10 7	Potharam	PM86	Historic	structure	A-BS	prim.	med/lg.	deep	18° 56' 11.1''	79° 00' 05.9"
17/02/10 1	Gudem Gutta	PM87	Metallurgical	smelting/crucible	A	dis.	med/lg.	sh.	18° 53' 53.2"	79° 10' 15.6"
17/02/10 2	Nambal	PM88	Metallurgical	smelting/crucible	A	dis.	med.	deep	18° 56' 10.8"	79° 08' 41.9"
17/02/10 3	Nambal	PM88	Metallurgical	smelting/crucible	A	dis.	lg.	deep	18° 56' 09.7"	79° 08' 40.4"
17/02/10 4	Dwaraka	PM89	Historic	settlement	A	dis.	lg.	sh.	18° 58' 48.3"	79° 06' 01.1"
17/02/10 5	Dwaraka	PM90	Metallurgical	smelting - scatter	BS	dis.	lg.	sh.	18° 58' 48.2"	79° 05' 58.9"
17/02/10 6	Dwaraka	PM90	Metallurgical	smelting - scatter	A	dis.	lg.	sh.	18° 58' 46.9"	79° 06' 03.4"
18/02/10 1	Rebbanapally	PM91	Metallurgical	smelting/crucible? - scatter	A	dis.	lg.	sh/med?	18° 56' 55.8"	79° 10' 23.3"
18/02/10 2	Rebbanapally	PM91	Metallurgical	smelting	A	dis.	med.	med?	18° 56' 56.1"	79° 10' 24.6"

Location	General placename	Site No	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
18/02/10 3	Pedda Bellal	PM92	Metallurgical	smelting	BS	prim.	lg.	deep	19° 04' 44.6"	78° 48' 12.7"
18/02/10 4	Pedda Bellal	PM93	Metallurgical	smelting	A	dis.	lg.	deep	19° 04' 46.1"	78° 48' 15.1"
18/02/10 5	Pedda Bellal	PM94	Metallurgical	smelting - scatter	BS-A	dis.	lg.	sh?	19° 04' 55.3"	78° 48' 15.9"
18/02/10 6	Pedda Bellal	PM95	Metallurgical	smelting - scatter	A	dis.	med?	sh/med?	19° 04' 50.8"	78° 48' 22.9"
18/02/10 7	Pedda Bellal	PM96	Metallurgical	smelting - scatter	SE-BS	dis.	med?	sh?	19° 04' 41.7"	78° 48' 35.2"
19/02/10 1	Pedda Nakkalapet	PM97	Metallurgical	smelting - scatter	A	dis.	?	sh.	18° 58' 50.6"	79° 02' 52.6"
19/02/10 2	Pedda Nakkalapet	PM98	Metallurgical	smelting - scatter	A	dis.	sm?	sh/med?	18° 58' 47.4"	79° 02' 53.1"
19/02/10 3	Chittial	PM99	Metallurgical	smelting	A	dis.	lg.	deep.	19° 04' 03.3"	78° 47' 27.3"
19/02/10 4	Chittial	PM100	Metallurgical	smelting	BS-SE	prim.	lg.	deep.	19° 03' 31.5"	78° 47' 22.8"
19/02/10 5	Chittial	PM100	Metallurgical	smelting	A-BS	dis.	lg.	deep.	19° 03' 25.7"	78° 47' 22.7"
19/02/10 6	Chittial	PM100	Metallurgical	smelting	A-BS	dis.	lg.	deep.	19° 03' 23.6"	78° 47' 27.6"
21/02/10 1	Gopalpur	PM101	Metallurgical	smelting/crucible? - scatter	SE-A	dis.	?	sh?	18° 14' 05.1"	78° 48' 32.9"
21/02/10 2	Gopalpur	PM102	Metallurgical	smelting/crucible - sec	S	sec.	-	-	18° 14' 8.19"	78° 48' 33.33"
21/02/10 3	Gopalpur	PM102	Metallurgical	smelting/crucible - scatter	S-BS	dis.	lg.	sh.	18° 14' 08.8"	78° 48' 33.8"
21/02/10 4	Gopalpur	PM102	Metallurgical	smelting/crucible - sec	S	sec.	-	-	18° 14' 08.9"	78° 48' 31.5"
21/02/10 5	Gopalpur	PM102	Metallurgical	smelting/crucible - sec	S	sec.	-	-	18° 14' 09.1"	78° 48' 30.4"
21/02/10 6	Gopalpur	PM102	Metallurgical	smelting/crucible	S	dis.	?	med?	18° 14' 09.4"	78° 48' 30.4"
21/02/10 7	Gopalpur	PM103	Metallurgical	crucible/smelting	S[E]	dis.	?	?	18° 14' 10.1"	78° 48' 26.3"
21/02/10 8	Gopalpur	PM103	Metallurgical/hist	crucible/smelting - sec	S[E]	sec.	-	-	18° 14' 09.6"	78° 48' 26.8"
21/02/10 9	Dacharam	PM104	Metallurgical	smelting	SE-A	dis.	?	med?	18° 15' 50.9"	78° 50' 50.9"
21/02/10 10	Dacharam	PM105	Prehistoric	megalithic	SB	prim.	lg.	N/A	18° 16' 13.3"	78° 51' 05.5"
22/02/10 1	Ibrahimpatnam	PM106	Metallurgical	crucible/smelting	S	dis.	lg.	deep	18° 54' 20.9"	78° 35' 00.7"
22/02/10 2	Ibrahimpatnam	PM107	Metallurgical/Ethno	operational smithy	S	N/A	N/A	N/A	18° 54' 24.0"	78° 35' 01.9"
22/02/10 3	Ibrahimpatnam	PM108	Metallurgical	smelting	SE-BS	dis.	lg.	sh.	18° 54' 32.2"	78° 34' 49.1"
22/02/10 4	Ibrahimpatnam	PM108	Metallurgical	smelting - scatter	SE-BS	dis.	lg.	sh.	18° 54' 29.0"	78° 34' 49.4"
22/02/10 5	Ibrahimpatnam	PM109	Historic	Temple	S	N/A	N/A	N/A	18° 54' 22.1"	78° 35' 01.3"
23/02/10 1	Bornapalli	PM110	Metallurgical	smelting - scatter	A	dis.	lg.	sh.	19° 01' 39.6"	78° 49' 06.9"

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Location	General placename	Site No	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
23/02/10 2	Bornapalli	PM111	Metallurgical	smelting - scatter	A-SE	dis/sec?	lg.	sh.	19° 1' 51.50"	78° 49' 8.45"
23/02/10 3	Bornapalli	PM112	Metallurgical	smelting	F	prim.	lg.	deep	19° 01' 09.4"	78° 48' 52.6"
23/02/10 4	Bornapalli	PM112	Metallurgical	smelting	F	prim.	lg.	deep	19° 01' 10.0"	78° 48' 52.6"
23/02/10 5	Bornapalli	PM112	Metallurgical	smelting	F	prim.	lg.	deep	19° 01' 10.4"	78° 48' 52.7"
23/02/10 6	Bornapalli	PM112	Metallurgical	smelting	F	prim.	lg.	deep	19° 01' 10.9"	78° 48' 52.7"
23/02/10 7	Bornapalli	PM112	Metallurgical	smelting	F	prim.	lg.	deep	19° 01' 11.7"	78° 48' 52.6"
23/02/10 8	Chinthaloor	PM113	Metallurgical	smelting	SE-BS	dis.	lg.	med?	18° 58' 48.1"	78° 50' 00.1"
23/02/10 9	Chinthaloor	PM113	Metallurgical	smelting	SE	dis.	lg.	med?	18° 58' 47.6"	78° 49' 59.3"
23/02/10 10	Chinthaloor	PM113	Metallurgical	smelting	S	dis.	lg.	deep	18° 58' 49.9"	78° 49' 58.6"
23/02/10 11	Oddelingapur	PM114	Geological/Met	ore deposit	SE-BS	dis/sec.	N/A	sh.	18° 57' 30.0"	78° 50' 01.3"
23/02/10 12	Oddelingapur	PM115	Metallurgical	smelting - scatter	A-SE	dis.	lg.	sh/med?	18° 57' 29.6"	78° 49' 58.1"
24/02/10 1	Oddelingapur	PM116	Metallurgical	smelting - scatter	A	dis.	lg.	sh.	18° 57' 47.6"	78° 50' 06.5"
24/02/10 2	Oddelingapur	PM117	Metallurgical	smelting - scatter	A	dis.	?	sh.	18° 57' 46.4"	78° 50' 13.4"
24/02/10 3	Bhupatipur	PM118	Metallurgical	smelting	A	dis.	lg.	deep	18° 56' 02.2"	78° 49' 56.8"
24/02/10 4	Bhupatipur	PM118	Metallurgical	smelting	A	dis.	lg.	sh.	18° 56' 00.3"	78° 49' 57.0"
25/02/10 1	Gutrajupalle	PM119	Metallurgical	crucible/smelting	SE-BS-A	dis.	lg?	sh/med?	18° 50' 23.7"	78° 59' 56.8"
25/02/10 2	Gutrajupalle	PM120	Metallurgical	smelting	SE	dis.	lg?	deep	18° 50' 15.6"	79° 00' 12.5"
25/02/10 3	Gutrajupalle	PM120	Metallurgical	smelting - scatter	SE	dis.	lg?	sh?	18° 50' 16.7"	79° 00' 12.9"
25/02/10 4	Gutrajupalle	PM120	Metallurgical	smelting	SE-BS	dis.	lg?	deep	18° 50' 19.7"	79° 00' 13.0"
25/02/10 5	Gutrajupalle	PM121	Geological/Met	quarry + smelting?	BSH-SE	dis/sec?	?	sh.	18° 50' 21.8"	79° 00' 13.9"
25/02/10 6	Gangapur	PM122	Geological	ore deposit	BSH-SE	N/A	lg.	N/A	18° 50' 20.0"	79° 01' 40.3"
25/02/10 7	Gangapur	PM123	Metallurgical	smelting - scatter	SE-BS	dis.	lg?	sh.	18° 50' 18.8"	79° 01' 39.9"
25/02/10 8	Gangapur	PM124	Metallurgical	smelting - scatter	S	dis.	?	sh?	18° 50' 12.5"	79° 01' 36.8"
26/02/10 1	Bheemaram	PM125	Metallurgical	smelting - scatter	SE	dis.	lg?	sh/med?	18° 43' 54.2"	78° 47' 10.4"
26/02/10 2	Venkatraopet	PM126	Metallurgical	smelting - sec	S	sec.	-	-	18° 43' 32.1"	78° 48' 16.3"
26/02/10 3	Oddyadu	PM127	Metallurgical	smelting - scatter	SE-A	dis.	lg.	sh.	18° 42' 09.6"	78° 48' 49.3"
26/02/10 4	Oddyadu	PM127	Metallurgical	smelting	A-SE	dis.	?	med?	18° 42' 12.1"	78° 48' 48.2"

Location	General placename	Site No	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
26/02/10 5	Oddyadu	PM128	Metallurgical	smelting/crucible - scatter	A	dis.	lg.	sh.	18° 41' 54.6"	78° 48' 38.3"
26/02/10 6	Oddyadu	PM128	Metallurgical	crucible/smelting - scatter	A	dis.	lg.	sh.	18° 41' 54.2"	78° 48' 39.3"
26/02/10 7	Oddyadu	PM129	Metallurgical	smelting	A	dis.	lg.	med?	18° 41' 56.0"	78° 49' 01.5"
26/02/10 8	Kondapur	PM130	Metallurgical	smelting	A-BSH	dis.	?	sh.	18° 46' 07.0"	78° 49' 38.5"
27/02/10 1	Cherlakondapoor	PM131	Metallurgical	smelting - scatter/sec	S	dis.	?	sh?	18° 53' 59.5"	78° 47' 33.6"
27/02/10 2	Cherlakondapoor	PM131	Metallurgical	smelting - scatter/sec	S	sec.	?	?	18° 53' 57.8"	78° 47' 30.8"
27/02/10 3	Fakirkondapur	PM132	Metallurgical	smelting	BS (SE)	dis.	?	sh?	18° 56' 44.6"	78° 37' 48.5"
27/02/10 4	Fakirkondapur	PM132	Metallurgical	smelting	BS (SE)	dis?	?	deep?	18° 56' 43.3"	78° 37' 48.7"
27/02/10 5	Fakirkondapur	PM133	Metallurgical/hist	smelting/crucible? - sec	BS (SE)	dis.	?	sh.	18° 56' 44.4"	78° 37' 44.4"
27/02/10 6	Yamapur	PM134	Metallurgical	smelting - scatter	A	dis.	lg.	sh/med?	18° 56' 12.1"	78° 36' 41.6"
27/02/10 7	Yamapur	PM134	Metallurgical	smelting - scatter	A	dis.	lg.	sh?	18° 56' 13.2"	78° 36' 42.1"
19/09/09 6	Sirivamchakota	PM135	Metallurgical	smelting - scatter	A-BS	dis.	med?	sh.	18° 52' 28.56"	79° 4' 10.30"
19/09/09 7	Shekalla	PM136	Geological	ore deposit	SBH	prim.	sm.	deep	18° 50' 31.55"	79° 3' 4.30"
19/09/09 9	Polasa	PM137	Metallurgical	smelting - scatter	SE-A	dis.	lg.	sh.	18° 49' 33.88"	78° 57' 31.00"
19/09/09 10	Polasa	PM138	Historical	temple	A-SE	N/A	N/A	N/A	18° 49' 52.55"	78° 57' 21.39"
20/09/09 3	Dustarabad	PM139	Metallurgical/ethno	smelting - scatter	S (SE)	dis.	lg.	sh.	19° 5' 25.69"	78° 51' 51.79"
21/09/09 4	Konasamudram	PM68	Metallurgical	crucible	S	dis.	sm.	deep	18° 43' 42.90"	78° 31' 25.92"

Appendix A.2 – Finalised Site Records

This appendix presents the 'site' records formulated in this study based on the 'location' records collected during the Pioneering Metallurgy survey. This includes information such as site group, site type, location setting type, preservation status, size, deposit depth and GPS coordinates as described in Chapter 4.

Site No	Locations	General placename	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
PM1	24/01/10 1 2 3 5	Kotilingala	Historic	settlement	SE-BS+A	dis.	lg.	deep	18° 51' 34.6"	79° 11' 51.4"
PM2	24/01/10 6	Kotilingala	Historic	temple	SE	dis.	lg.	deep	18° 51' 45.4"	79° 11' 54.1"
PM3	25/01/10 1 5 6	Buggaram	Metallurgical	smelting	BS	prim.	lg.	deep	18° 52' 05.2"	79° 03' 33.5"
PM4	25/01/10 2 3	Buggaram	Historic	pottery scatter	BS + A	dis.	lg.	med.	18° 52' 00.5"	79° 03' 34.0"
PM5	25/01/10 4	Buggaram	Geological	quarry (modern)	BSH	prim.	lg.	deep	18° 52' 02.83"	79° 03' 23.4"
PM6	26/01/10 1 2 3 4	Sirikonda	Geological	ore deposit	BSH	prim.	lg.	deep	18° 51' 31.86"	79° 06' 20.09"
PM7	26/01/10 6	Sirikonda	Metallurgical/Ethno	operational smithy	S	prim.	med.	med.	18° 51' 22.7"	79° 06' 30.6"
PM8	26/01/10 7	Sirikonda	Metallurgical	smelting	S	dis.	med.	med.	18° 51' 23.1"	79° 06' 28.4"
PM9	26/01/10 8	Sirikonda	Metallurgical	smelting/crucible	S	dis.	med.	deep	18° 51' 22.4"	79° 06' 31.3"
PM10	28/01/10 1	Kalleda	Metallurgical	smelting	BS	dis.	med.	med.	18° 51' 35.2"	79° 00' 54.8"
PM11	28/01/10 2	Kalleda	Metallurgical	smelting	A	dis/sec?	med.	sh/med.	18° 51' 35.8"	79° 00' 58.6"
PM12	28/01/10 3	Kalleda	Geological	quarry	BSH	sec?	N/A	section	18° 51' 34.1"	79° 01' 9.01"
PM13	28/01/10 4	Yeshwantareopeta	Geological	quarry	BSH - SE	N/A	N/A	section	18° 50' 49.0"	79° 02' 27.1"
PM14	28/01/10 5	Shekalla	Metallurgical	smelting	S	dis.	sm.	deep	18° 50' 21.4"	79° 04' 20.6"
PM15	28/01/10 6	Shekalla	Metallurgical/Ethno	operational smithy	S	N/A	N/A	N/A	18° 50' 31.3"	79° 04' 14.2"
PM16	28/01/10 7	Shekalla	Metallurgical/Ethno	operational smithy	S	N/A	N/A	N/A	18° 50' 28.1"	79° 04' 14.9"
PM17	28/01/10 8	Shekalla	Geological	mining pits	BSH	N/A	N/A	N/A	18° 50' 36.3"	79° 04' 40.8"
PM18	29/01/10 1 2 3	Chinna Nakkalapet	Metallurgical	smelting/crucible	A-SE	dis.	lg.	deep	18° 58' 40.1''	79° 04' 21.1''

Site No	Locations	General placename	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
PM19	29/01/10 4	Chinna Nakkalapet	Metallurgical	smelting/crucible	A-SE	dis.	med.	sh.	18° 58' 36.9''	79° 04' 23.3''
PM20	29/01/10 5	Chinna Nakkalapet	Historic	settlement	A	prim.	med.	N/A	18° 58' 13.4''	79° 04' 32.9"
PM21	30/01/10 1	Narella	Metallurgical	smelting - sec	S	sec.	lg.	sh.	18° 55' 20.5"	79° 01' 58.5"
PM22	30/01/10 2	Narella	Metallurgical	smelting	S	dis.	lg.	sh.	18° 55' 23.4''	79° 01' 53.3''
PM23	30/01/10 3	Narella	Metallurgical/Ethno	operational smithy	BS-SE	N/A	N/A	N/A	18° 55' 32.0''	79° 01' 28.7''
PM24	01/02/10 1 2	Arnakonda	Metallurgical	smelting	SE-A	dis.	lg.	deep	18° 37' 07.0"	79° 09' 47.8"
PM26	01/02/10 3 4	Arnakonda	Metallurgical	smelting	S	dis.	lg.	deep	18° 37' 03.8"	79° 09' 52.2"
PM27	01/02/10 5	Arnakonda	Metallurgical	smelting	S	dis/sec?	sm.	deep	18° 36' 48.3"	79° 09' 49.7"
PM28	01/02/10 6	Mallapur	Metallurgical	smelting	A	prim.	lg.	deep	18° 38' 50.8"	79° 09' 39.6"
PM29	01/02/10 7	Mallapur	Geological	mining pits	A	dis.	lg.	N/A	18° 38' 44.8"	79° 09' 42.5"
PM30	01/02/10 8	Mallapur	Metallurgical	smelting	A	dis.	lg.	deep	18° 39' 49.2"	79° 09' 50.9"
PM25	01/02/10 9	Arnakonda	Historic	temple	SE-A	prim.	sm.	N/A	18° 37' 05.5"	79° 09' 47"
PM31	02/02/10 1	Abbapur	Metallurgical	smelting - scatter	A	dis.	lg.	sh.	18° 39' 49.0"	79° 11' 54.8"
PM32	02/02/10 2	Abbapur	Historic	settlement?	A	prim.	lg.	N/A	18° 39' 49.9"	79° 12' 00.7"
PM33	02/02/10 3	Abbapur	Findspot	findspot	A	sec.	sm.	sh.	18° 39' 14.9"	79° 12' 25.9"
PM34	02/02/10 4 5 6 7	Kammarikhampet	Metallurgical	smelting	S - SE	dis.	lg	deep	18° 38' 07.9"	79° 11' 51.9"
PM35	02/02/10 8	Mallapur	Metallurgical	smelting - scatter	A	sec.	lg.	sh.	18° 39' 37.7"	79° 09' 26.1"
PM36	02/02/10 9	Mallapur	Geological	ore deposit	BS-A	prim.	lg.	deep	18° 39' 44.7"	79° 09' 25.5"
PM37	03/02/10 16	Lachakkapet	Historic	fort	A	prim.	N/A	N/A	18° 52' 29.9"	78° 54' 39.2"
PM38	03/02/10 1 2	Lachakkapet	Metallurgical	smelting - scatter	A	sec.	lg.	sh.	18° 52' 29.9"	78° 54' 39.2"
PM39	03/02/10 3	Lachakkapet	Metallurgical	smelting	A	dis.	lg.	deep	18° 52' 26.6"	78° 54' 47.0"
PM40	03/02/10 4 7	Lachakkapet	Metallurgical	smelting	A	dis.	lg.	deep	18° 52' 36.2"	78° 54' 59.4"
PM41	03/02/10 5	Lachakkapet	Historic	pottery scatter	A	sec.	lg.	sh.	18° 52' 38.02"	78° 55' 03.54"
PM42	03/02/10 6	Lachakkapet	Metallurgical	smelting	A	dis.	lg.	deep	18° 52' 43.2''	78° 55' 06.4"
PM43	03/02/10 8	Rangapeta	Metallurgical/Ethno	operational smithy	S	N/A	N/A	N/A	18° 53' 44.6''	78° 54' 30.5"

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Site No	Locations	General placename	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
PM44	03/02/10 9 10	Rangapeta	Metallurgical	smelting	SE-A + BS	dis.	lg.	deep	18° 53' 42.0''	78° 54' 29.3"
PM45	03/02/10 11 12	Raikal	Metallurgical	smelting	SE-BS	dis.	lg.	deep	18° 54' 40.8''	78° 48' 37.2''
PM46	03/02/10 13 14 15	Ayodya/Uppumadugu	Metallurgical	smelting	A	dis.	ig.	deep	18° 53' 27.3''	78° 51' 40.7''
PM47	05/02/10 1	Rechapally	Metallurgical	smelting	A	dis.	lg.	deep	18° 56' 47.2''	78° 56' 06.6''
PM48	05/02/10 2	Rechapally	Metallurgical	smelting	A	dis.	lg.	deep	18° 56' 55.1''	78° 56' 07.0''
PM49	05/02/10 3 4	Rechapally	Metallurgical	smelting	SE-A	dis.	lg.	deep	18° 56' 13.7''	78° 55' 43.1''
PM50	05/02/10 5	Rechapally	Metallurgical	smelting - scatter	S	sec.	lg.	sh.	18° 55' 52.5''	78° 55' 49.0''
PM51	05/02/10 6	Konapur	Metallurgical	smelting	SE-A	dis.	med.	med.	18° 52' 24.0''	78° 55' 58.1''
PM52	05/02/10 7	Konapur	Metallurgical	smelting	A	prim.	lg.	deep	18° 52' 18.8''	78° 56' 03.0''
PM53	06/02/10 1	Kalleda	Historic	pottery scatter	A	sec.	sm/med.	sh.	18° 50' 36.4''	79° 00' 20.1''
PM54	06/02/10 2 3 4	Kalleda	Metallurgical	smelting/crucible	A	prim.	lg.	deep	18° 50' 34.3''	79° 00' 11.6''
PM55	08/02/10 1 2 3	Nawabpet	Metallurgical	smelting/crucible	A	prim.	lg.	deep	19° 07' 21.1''	78° 49' 33.2''
PM56	08/02/10 4 5 6 7	Nawabpet	Metallurgical	smelting	F	prim.	lg.	deep	19° 08' 25.7''	78° 49' 04.7''
PM57	08/02/10 8	Kalleda	Metallurgical	smelting	A	dis.	lg.	deep	19° 08' 04.2''	78° 52' 17.4''
PM58	08/02/10 9 10	Kalleda	Metallurgical	smelting/crucible	A	dis.	lg.	med.	19° 08' 09.4''	78° 52' 15.9''
PM59	08/02/10 11	Kalleda	Findspot	findspot	A	sec.	sm.	sh.	19° 08' 08.5''	78° 52' 16.6''
PM60	09/02/10 1 2 4	Konapur	Metallurgical	crucible/smelting	SE-A + S	dis.	lg.	deep	18° 43' 10.5''	78° 37' 06.4''
PM61	09/02/10 3	Konapur	Metallurgical	smelting	SE-A	dis.	lg.	deep	18° 43' 16.4''	78° 37' 09.9''
PM62	09/02/10 5	Konapur	Metallurgical	crucible/smelting	A	dis.	lg.	med.	18° 43' 07.1''	78° 36' 49.3''
PM63	09/02/10 6	Konapur	Metallurgical	smelting/crucible?	A	dis.	lg.	med.	18° 43' 09.4''	78° 36' 33.8''
PM64	09/02/10 7	Konapur	Metallurgical	smelting	A	dis.	lg.	med.	18° 43' 01.6''	78° 37' 42.3''
PM65	10/02/10 1 2	Konasamudram	Metallurgical	crucible/smelting	SE-BS	dis.	lg.	deep	18° 43' 48.5"	78° 31' 27.1"
PM66	10/02/10 3	Konasamudram	Historic	structure	S	N/A	N/A	N/A	18° 43' 40.5"	78° 31' 25.0"
PM67	10/02/10 4	Konasamudram	Metallurgical	crucible/smelting	SE-A	dis.	lg.	med.	18° 43' 41.2"	78° 31' 28.4"
PM68	21/09/09 4	Konasamudram	Metallurgical	crucible	S	dis.	sm.	deep	18° 43' 42.90"	78° 31' 25.92"

B. Girbal

Site No	Locations	General placename	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
PM69	11/02/10 1	Nagaram	Metallurgical	smelting	S	dis.	sm.	med.	18° 55' 30.2"	79° 04' 22.8"
PM70	11/02/10 2 3	Nagaram	Metallurgical	smelting - scatter	A	dis.	?	sh.	18° 55' 11.6"	79° 04' 09.8"
PM71	11/02/10 4	Nagaram	Metallurgical/Ethno	operational smithy	S	N/A	N/A	N/A	18° 55' 35.2"	79° 04' 30.3"
PM72	11/02/10 5	Maddunur	Metallurgical	smelting	BSH	prim.	lg.	deep.	18° 52' 13.5"	79° 05' 55.1"
PM73	11/02/10 6	Maddunur	Metallurgical	smelting	BS-SE	dis.	med/lg.	deep.	18° 51' 49.1"	79° 06' 13.2"
PM74	12/02/10 1 2 6 7 8 9 10	Parasurampalli	Metallurgical	smelting	BS- A+SE	dis.	lg.	deep	18° 21' 30.4"	79° 53' 28.6"
PM75	12/02/10 3 4 5	Parasurampalli	Metallurgical	crucible/smelting	A	prim.	lg.	deep	18° 21' 25.0"	79° 53' 29.2"
PM76	13/02/10 1	Rangasagar	Metallurgical	smelting	A	dis.	med/lg.	sh/med?	19° 01' 32.3"	78° 55' 28.2"
PM77	13/02/10 2 3 4	Rangasagar	Metallurgical	smelting	A	dis.	lg.	deep.	19° 01' 40.8"	78° 55' 21.7"
PM78	13/02/10 5	Rangasagar	Historic	settlement	BS-A	N/A	N/A	N/A	19° 01' 40.1"	78° 55' 17.7"
PM79	13/02/10 6 7 8 9 10 11 12 13 14 15	Davanpally	Metallurgical	smelting	F	prim.	lg.	deep	19° 00' 41.2"	78° 52' 06.3"
PM80	15/02/10 1 2 3 4 5	Kairigudam	Metallurgical	smelting	F	prim.	lg.	deep	18° 58' 39.0''	78° 54' 03.3''
PM81	15/02/10 6	Katkapur	Prehistoric/Met	stone tool scatter	A	dis.	lg.	sh.	18° 59' 50.7''	78° 53' 02.6"
PM82	16/02/10 1	Potharam	Metallurgical	smelting	SE-A	dis.	lg.	deep	18° 56' 54.8''	78° 59' 00.5"
PM83	16/02/10 2 3	Potharam	Metallurgical	smelting	A-SE	dis.	lg.	deep	18° 57' 06.7''	78° 58' 34.0"
PM84	16/02/10 4 5	Potharam	Metallurgical	smelting/crucible	A-SE	dis.	lg.	deep	18° 57' 12.1''	78° 58' 34.2"
PM85	16/02/10 6	Potharam	Metallurgical	smelting - scatter	A	dis.	lg.	sh.	18° 56' 10.2''	79° 00' 05.8"
PM86	16/02/10 7	Potharam	Historic	structure	A-BS	prim.	med/lg.	deep	18° 56' 11.1''	79° 00' 05.9"
PM87	17/02/10 1	Gudem Gutta	Metallurgical	smelting/crucible	A	dis.	med/lg.	sh.	18° 53' 53.2"	79° 10' 15.6"
PM88	17/02/10 2 3	Nambal	Metallurgical	smelting/crucible	A	dis.	lg.	deep	18° 56' 10.8"	79° 08' 41.9"
PM89	17/02/10 4	Dwaraka	Historic	settlement	A	dis.	lg.	sh.	18° 58' 48.3"	79° 06' 01.1"
PM90	17/02/10 5 6	Dwaraka	Metallurgical	smelting - scatter	A + BS	dis.	lg.	sh.	18° 58' 46.9"	79° 06' 03.4"
PM91	18/02/10 1 2	Rebbanapally	Metallurgical	smelting/crucible	A	dis.	lg.	med?	18° 56' 55.8"	79° 10' 23.3"

Site No	Locations	General placename	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
PM92	18/02/10 3	Pedda Bellal	Metallurgical	smelting	BS	prim.	lg.	deep	19° 04' 44.6"	78° 48' 12.7"
PM93	18/02/10 4	Pedda Bellal	Metallurgical	smelting	A	dis.	lg.	deep	19° 04' 46.1"	78° 48' 15.1"
PM94	18/02/10 5	Pedda Bellal	Metallurgical	smelting - scatter	BS-A	dis.	lg.	sh?	19° 04' 55.3"	78° 48' 15.9"
PM95	18/02/10 6	Pedda Bellal	Metallurgical	smelting - scatter	A	dis.	med?	sh/med?	19° 04' 50.8"	78° 48' 22.9"
PM96	18/02/10 7	Pedda Bellal	Metallurgical	smelting - scatter	SE-BS	dis.	med?	sh?	19° 04' 41.7"	78° 48' 35.2"
PM97	19/02/10 1	Pedda Nakkalapet	Metallurgical	smelting - scatter	A	dis.	?	sh.	18° 58' 50.6"	79° 02' 52.6"
PM98	19/02/10 2	Pedda Nakkalapet	Metallurgical	smelting - scatter	A	dis.	sm?	sh/med?	18° 58' 47.4"	79° 02' 53.1"
PM99	19/02/10 3	Chittial	Metallurgical	smelting	A	dis.	lg.	deep.	19° 04' 03.3"	78° 47' 27.3"
PM100	19/02/10 4 5 6	Chittial	Metallurgical	smelting	A + BS	prim.	lg.	deep.	19° 03' 25.7"	78° 47' 22.7"
PM101	21/02/10 1	Gopalpur	Metallurgical	smelting/crucible - sca	SE-A	dis.	?	sh?	18° 14' 05.1"	78° 48' 32.9"
PM102	21/02/10 2 3 4 5 6	Gopalpur	Metallurgical	smelting/crucible	S	dis.	lg.	med?	18° 14' 09.4"	78° 48' 30.4"
PM103	21/02/10 7 8	Gopalpur	Metallurgical	crucible/smelting	S[E]	dis.	lg.	?	18° 14' 10.1"	78° 48' 26.3"
PM104	21/02/10 9	Dacharam	Metallurgical	smelting	SE-A	dis.	?	med?	18° 15' 50.9"	78° 50' 50.9"
PM105	21/02/10 10	Dacharam	Prehistoric	megalithic	SB	prim.	lg.	N/A	18° 16' 13.3"	78° 51' 05.5"
PM106	22/02/10 1	Ibrahimpatnam	Metallurgical	crucible/smelting	S	dis.	lg.	deep	18° 54' 20.9"	78° 35' 00.7"
PM107	22/02/10 2	Ibrahimpatnam	Metallurgical/Ethno	operational smithy	S	N/A	N/A	N/A	18° 54' 24.0"	78° 35' 01.9"
PM108	22/02/10 3 4	Ibrahimpatnam	Metallurgical	smelting	SE-BS	dis.	lg.	sh.	18° 54' 32.2"	78° 34' 49.1"
PM109	22/02/10 5	Ibrahimpatnam	Historic	Temple	S	N/A	N/A	N/A	18° 54' 22.1"	78° 35' 01.3"
PM110	23/02/10 1	Bornapalli	Metallurgical	smelting - scatter	A	dis.	lg.	sh.	19° 01' 39.6"	78° 49' 06.9"
PM111	23/02/10 2	Bornapalli	Metallurgical	smelting - scatter	A-SE	dis/sec?	lg.	sh.	19° 1' 51.50"	78° 49' 8.45"
PM112	23/02/10 3 4 5 6 7	Bornapalli	Metallurgical	smelting	F	prim.	lg.	deep	19° 01' 10.4"	78° 48' 52.7"
PM113	23/02/10 8 9 10	Chinthaloor	Metallurgical	smelting	SE-BS + S	dis.	lg.	med?	18° 58' 48.1"	78° 50' 00.1"
PM114	23/02/10 11	Oddelingapur	Geological/Met	ore deposit	SE-BS	dis/sec.	N/A	sh.	18° 57' 30.0"	78° 50' 01.3"
PM115	23/02/10 12	Oddelingapur	Metallurgical	smelting - scatter	A-SE	dis.	lg.	sh/med?	18° 57' 29.6"	78° 49' 58.1"
PM116	24/02/10 1	Oddelingapur	Metallurgical	smelting - scatter	A	dis.	lg.	sh.	18° 57' 47.6"	78° 50' 06.5"

Site No	Locations	General placename	Site Group	Site type	Setting	Status	Size	Depth	Latitude	Longitude
PM117	24/02/10 2	Oddelingapur	Metallurgical	smelting - scatter	A	dis.	?	sh.	18° 57' 46.4"	78° 50' 13.4"
PM118	24/02/10 3 4	Bhupatipur	Metallurgical	smelting	A	dis.	lg.	deep	18° 56' 02.2"	78° 49' 56.8"
PM119	25/02/10 1	Gutrajupalle	Metallurgical	crucible/smelting	SE-BS-A	dis.	lg?	sh/med?	18° 50' 23.7"	78° 59' 56.8"
PM120	25/02/10 2 3 4	Gutrajupalle	Metallurgical	smelting	SE	dis.	lg?	deep	18° 50' 15.6"	79° 00' 12.5"
PM121	25/02/10 5	Gutrajupalle	Geological/Met	quarry + smelting?	BSH-SE	dis/sec?	?	sh.	18° 50' 21.8"	79° 00' 13.9"
PM122	25/02/10 6	Gangapur	Geological	ore deposit	BSH-SE	N/A	lg.	N/A	18° 50' 20.0"	79° 01' 40.3"
PM123	25/02/10 7	Gangapur	Metallurgical	smelting - scatter	SE-BS	dis.	lg?	sh.	18° 50' 18.8"	79° 01' 39.9"
PM124	25/02/10 8	Gangapur	Metallurgical	smelting - scatter	S	dis.	?	sh?	18° 50' 12.5"	79° 01' 36.8"
PM125	26/02/10 1	Bheemaram	Metallurgical	smelting - scatter	SE	dis.	lg?	sh/med?	18° 43' 54.2"	78° 47' 10.4"
PM126	26/02/10 2	Venkatraopet	Metallurgical	smelting - sec	S	sec.	-	-	18° 43' 32.1"	78° 48' 16.3"
PM127	26/02/10 3 4	Oddyadu	Metallurgical	smelting	A-SE	dis.	lg.	med?	18° 42' 12.1"	78° 48' 48.2"
PM128	26/02/10 5 6	Oddyadu	Metallurgical	smelting/crucible - sca	A	dis.	lg.	sh.	18° 41' 54.6"	78° 48' 38.3"
PM129	26/02/10 7	Oddyadu	Metallurgical	smelting	A	dis.	lg.	med?	18° 41' 56.0"	78° 49' 01.5"
PM130	26/02/10 8	Kondapur	Metallurgical	smelting	A-BSH	dis.	?	sh.	18° 46' 07.0"	78° 49' 38.5"
PM131	27/02/10 1 2	Cherlakondapoor	Metallurgical	smelting - scatter/sec	S	sec.	lg?	sh?	18° 53' 59.5"	78° 47' 33.6"
PM132	27/02/10 3 4	Fakirkondapur	Metallurgical	smelting	BS (SE)	dis?	?	deep?	18° 56' 43.3"	78° 37' 48.7"
PM133	27/02/10 5	Fakirkondapur	Metallurgical/hist	smelting/crucible - sec	BS (SE)	dis.	?	sh.	18° 56' 44.4"	78° 37' 44.4"
PM134	27/02/10 6 7	Yamapur	Metallurgical	smelting - scatter	A	dis.	lg.	sh/med?	18° 56' 12.1"	78° 36' 41.6"
PM135	19/09/09 6	Sirivamchakota	Metallurgical	smelting - scatter	A-BS	dis.	med?	sh.	18° 52' 28.56"	79° 4' 10.30"
PM136	19/09/09 7	Shekalla	Geological	ore deposit	SBH	prim.	sm.	deep	18° 50' 31.55"	79° 3' 4.30"
PM137	19/09/09 9	Polasa	Metallurgical	smelting - scatter	SE-A	dis.	lg.	sh.	18° 49' 33.88"	78° 57' 31.00"
PM138	19/09/09 10	Polasa	Historic	temple	A-SE	N/A	N/A	N/A	18° 49' 52.55"	78° 57' 21.39"
PM139	20/09/09 3	Dustarabad	Metallurgical/ethno	smelting - scatter	S (SE)	dis.	lg.	sh.	19° 5' 25.69"	78° 51' 51.79"

Appendix A.3 – Brief Location and Site Descriptions

This appendix presents each 'location' description in brief by site record.

PM1:

24/01/10 (1) - Well-known Early Historic settlement site of Satavahana period (2-3rd century AD). Prominent raised sub-rectangular mound with ramparts and outer ditch. Modern village occupies eastern part of mound. This location marks highest part of mound within modern village.

24/01/10 (2) - Element of Early historic settlement site. Surface scatter of pottery in field on outer slope of settlement rampart. Three 'tiered' fields suggest stepped outer rampart.

24/01/10 (3) - Large scatter of artefactual material in cotton field within settlement mound. Concentrated in vicinity of well which was reportedly (Jaikishan) excavated by State Archaeology Department (1979-82).

24/01/10 (5) - This location marks the right-angled SW corner of the raised settlement mound. Rampart c.3m high at this point but outer ditch disturbed by later road following outer southern edge of the mound.

PM2:

24/01/10 (6) - Northeast corner of settlement mound of Kotilingala. Outer rampart runs west to follow Godavari River and south on line a small tributary river. Later temple of Koteshivava built on 'corner' mound overlooking Godavari. Evidence for brick construction below temple, possible part of rampart.

PM3:

25/01/10 (1) – Dense scatter of slag visible along roadside. Probably redeposited material from large smelting site nearby (25/01/10 (6)). May record furthest extent of site but uncertain as only sparse slag between this and 25/01/10 (6)

25/01/10 (5) – Highly visible cluster of grinding holes and hollows in flat surface of extensive granite outcrop c.50m from main smelting centre (25/01/10 (6)). Holes concentrated towards S end of outcrop. Most elliptical but wide variety of depths and orientations. Most individual holes but some broad scoops contain multiple grinding hollows. Depths up to 0.6m. Many appear angled as if grinding from one side. All show internal black staining with upper red oxidised halo at rim.

25/01/10 (6) – Large smelting site at base of hill. Distinct slag heap c.3m high but deepest area quarried out in modern times. Spread of heap c.40m diameter. Investigation of exposed sections show no clear stratification but increasing furnace wall and tuyere component upslope. Downslope loose-packed slag predom. Recent water conservation trenches (c.1m wide, 0.4m deep) along contours disturb and expose site. Away from central slag heap increasing inclusions of pottery. Upslope trench exposes possible furnace position w. collapsed furnace in section.

PM4:

25/01/10 (2) - Finds of pottery revealed in section of modern water conservation trench c.1m wide and 0.5m deep. Section shows two layers above decomposed natural bedrock. Pottery concentrated in lower (c.0.2m thick) layer. Section devoid of technological debris. In area of flat land c.100m south of smelting centre 25/01/10 (6). Maybe assoc. habitation area. No structural remains.

25/01/10 (3) - Scattered finds of pottery throughout paddy fields at base of hill. Probably derived from area of in situ material at 25/01/10 (2). Some technological debris also observed, including possible lumps of non-magnetic ore.

PM5:

25/01/10 (4) - Modern quarry scar examined as geological feature over c.30m length at base of low hillock. Upper part of exposed horizon deep red iron-stained lateritic soil, non-magnetic. Lower horizon coarse, pale cream decayed quartz-rich bedrock.

PM6:

26/01/10 (1) - One of 3 points marking the summit of Sirukonda Gutta. Banded magnetite outcrops across all southerly hillslopes examined. Soil reddish brown.

26/01/10 (2) - Second of 3 points marking the summit of Sirukonda Gutta. Banded magnetite outcrops across all southerly hillslopes examined.

26/01/10 (3) - Third of 3 points marking the summit of Sirukonda Gutta. Banded magnetite outcrops across all southerly hillslopes examined. Large granitic boulders appear to outcrop above visible surface banded magnetite.

26/01/10 (4) - Three modern quarry scoops exposing soil sections at base of hill. Section shows upper 0.3m reddish brown horizon containing abundant magnetite cobbles. Lower horizon loose cream-coloured quartz-rich decomposed bedrock.

PM7:

26/01/10 (6) - Site of operational blacksmith's forge by the side of road near centre of village beneath large shade tree. Comprises 2 ground level hearths, each with a square anvil set in a large wooden block embedded in the ground. One hearth blown by mechanical bellows driven by bicycle wheel and drive belt. One stone sharpening block with central cup for quenching liquid set in ground. The senior blacksmith, Kottapalli Lingaiah, was interviewed and photo-records made.

PM8:

26/01/10 (7) - Mound of slag in area of rough ground adjoining road. Former house compound. Slag probably cleared and redeposited from this a neighbouring plots. Scattered surface slag visible but not continuous over an area of several compounds. Slag occurs in dry stone compound walls and small fragments incorporated in mud walls of houses. A primary deposit marking the centre of activity may lie beneath the mound or nearby.

PM9:

26/01/10 (8) - This location comprises two elements. First is a small mound, c.7x6m, of smelting slag within compound of former village land lord. The mound is apparently in situ and the debris is well consolidated. No crucible fragments were observed in the mound. Second is the abundant occurrence of pottery, slag and distinct crucible fragments incorporated into the mud walls of this and the neighbouring compound, including the remnants of the walls of a much older building.

PM10:

28/01/10 (1) – Cultivated area (maybe 6/7 yrs old) very little slag. Large areas of previously existing heap quarried away for building road and cultivation. Soil changes near slag heap from reddish brown to deeper reddish brown, having slight magnetic property, which was absent in the lighter coloured soil.

PM11:

28/01/10 (2) - Elongated slag heap c.16m long and 6m wide. Some yellow/ white grey formations-possible limestones also found. Possibly redeposited material as highly disturbed by paddy field cultivation.

PM12:

28/01/10 (3) - Quarry site-possible laterite ore, ore low grade, sandy and gritty

PM13:

28/01/10 (4) - Quarry site - magnetic gravel. Small, loose magnetite pieces all over hillside. No evidence of extraction further up the slope.

PM14:

28/01/10 (5) - A small disturbed metallurgical debris mound in a village garden c.10m squared and up to 2m in height. There was debris and scattered material found up to 30m away from this location suggesting heavy disturbance. Material was primarily tap slag cakes (c.8cm thick) mixed with furnace slag in a very dark grey/black soil matrix. Some banded magnetite also noticed.

PM15:

28/01/10 (6) - Floor level smithy still in use and interview of smith.

PM16:

28/01/10 (7) - Working floor level smithy and smith interviewed.

PM17:

28/01/10 (8) - Small quarrying pits were observed on the NE side of the hill. These small depressions have banded magnetite nodules in them and may have been for ore extraction. Below the depressions (downhill) are spoil heaps presumably material removed from the pits. These are elongated and arced following the outline of the circular depressions.

PM18:

29/02/10 (1) - Extensive slag scatter in the field, adjacent to and derived from mound of tech. debris [29/01/10 (2) and 29/01/10 (3)]

29/02/10 (2) - Substantial mound of tech.debris. This record describes the mound's northern extent. Cultivation has apparently removed large amount of material and left exposed sections. Furnace slag and poss. lining remnants visible in these sections. A section cut and cleared on E flank of mound. crucible frags appear more dominant in this part of the mound than its southern extent. Slag scatter of 29/01/10 (1) derives from this mound. Length of entire mound c.50m; max. width 15m. Height in this area 0.5-1m.

29/02/10 (3) - Substantial mound of tech.debris. This record describes the mound's southern extent. Appears less disturbed than northern extent (29/01/10 (2)). This is the highest point of the mound, >1.5m. Noticeably less crucible frags in this part of the mound. Length of entire mound c.50m; width at widest part c.15m.

PM19:

29/02/10 (4) - Slag scatter close to well SE of 29/1/10 (2) and 29/1/10 (3), indicating poss. site of former mound.

PM20:

29/01/10 (5) - Group of large foundation stones at a field edge indicating presence of former habitation site. Pottery scatter in field immediately N. Possibly former site of village (int.ref.8). Group of upright stone slabs visible to SE, arranged in a square on concrete base; lintels of wood; central upright stone with Hanuman carving, indicating former temple.

PM21:

30/01/10 (1) - Abundant quantities of slag frags, banded magnetite ore and occasional pottery frags observed in mud brick and drystone house and compound walls in village streets as well as paths. Some slags also observed in walls of ruined 13th-14th century tower. This material possibly derives from concentration of material at 30/01/10 (2). A greater concentration of material observed in walls the closer one gets to 30/1/10 (2). Villagers say that the ore came from Peddagutta hill which can be collected from surface.

PM22:

30/01/10 (2) - Spread of slag and pottery fragments in an area of rough ground dissected by a low dry stone wall, E of school and W of area described in record 30/1/10 (1). Highest density of slag observed in centre of area, where there is also a modern well. Spread appears to be levelled remains of primary mound spread over at least 50m.

PM23:

30/0110 (3) - Itinerant blacksmith with portable equipment at work outside Yellamma temple. Anvil with large flat stone beneath, and stones around hearth area, look like permanent fixtures (?), Int.ref.9.

PM24:

01/02/10 (1) - Substantial mound of tech. debris. Highly disturbed w. large amount of material removed. Steeply cut N edge w. concentrations of tap slag and some fragments of furnace wall. Abundance of tap and furnace slag along S edge of mound; spread of same material in adjacent field immediately to S (01/02/10 (2)). Mound possibly twice its present size originally and roughly circular; this observation supported by landowners comments. (int.ref.10). Length of remaining mound c.35cm; max. height 2.5m.

01/02/10 (2) - Scatter of slag frags. probably deriving from mound 01/02/10 (1), distributed evenly over cultivated field (cotton) immediately to S of mound.

PM25:

01/02/10 (9) - Small rectangular temple c.100m S of mound 01/02/10 (1) and at S edge of field 01/02/10 (2). All four walls standing. Size approx. 3mx2m; longer sides made of horizontal laid slabs, shorter sides constructed of upright slabs. Roof of stone lintels. One entrance at E side, with a tree growing out from within. Carving of monkey god Hanuman observed on the outer face of one wall. Temple thought to date from 7th - 8th century.

PM26:

01/02/10 (3) - Flattened, elongated mound of tech. debris, extending N-S; highest point towards southern end: max height c.2m. This is a composite location consisting of several mound remnants. Difficult to define original extent of mound.

01/02/10 (4) - Abundant spread of tech.debris in small area of rough ground adjacent to and immediately W of 01/02/10 (3). A higher proportion of furnace debris was observed in the assemblage of material here than at any other location in Arnakonda; this suggests a possible smelting site. No crucible remains observed.

PM27:

01/02/10 (5) - Small mound of tech.debris near modern well by N-S track through village. Disturbed and mixed technological debris found. Was probably part of a much larger mound. Large frag. of slag furnace structure, c.50x25cm, observed beside track on E side, little to S of mound.

PM28:

01/02/10 (6) - Large sub-circular mound of tech.debris dissected by construction of SH7. Mound on W side of road largely intact and appear to represent up to a third of original mound. Mound material observed in adjacent fields, on W side of road, where a large piece of probable furnace structure (55cm x 30cm surface area) also identified. Mound on E side of road largely removed, with only the base of the mound visible; adjacent land bulldozed and levelled; mound material scattered on surface and probably incorporated into road construction. Levelled land bordered by rice fields. A small quarry and 2 wells observed in immediate vicinity of mound, E side of road. Original length of the mound c.90m (N-S); width c.50m (E-W), max height 3.5m.

PM29:

01/02/10 (7) - Small hill, recently terraced for mango cultivation. Source of banded magnetite with loose nodules scattered over surface. One area, at the top of the hill remains relatively undisturbed. Here, there are traces of 3-4 small partially filled in pits. These may be evidence for mining or quarrying of ore.

PM30:

01/02/10 (8) - Large mound of tech debris, cut by minor road and by lane at right angles to road. Profile of mound visible in a cut section in lane; mounded material observed along field banks. Original mound length c.50m, N-S; width c.45m, E-W. Max height of remaining mound >2m; probably 3-4m high originally.

PM31:

02/02/10 (1) - Abundant scatter of tech.debris in a cotton field. Field c.70m x 50m, crossed by water pipe running roughly E-W. Ground much disturbed; hard to locate central point for distribution of material. No visible mound, but ground appeared to slope v. gently downwards from centre of field. Concentration of material increased towards the N.side of field; trailed off towards S.

PM32:

02/02/10 (2) - Group of large stones and pottery frags. Observed on the ground c.150m of 02/02/10 (1), possibly indicating a former settlement or habitation site. Presence of stones suggests a high status structure, possibly a temple or a headman's house.

PM34:

02/02/10 (4) - Tech. debris observed in low drystone wall adjacent to and on NE side of track and in area extending N track (immediately W of 02/02/10 (5)).

02/02/10 (5) - Small mound of tech. debris immediately adjacent to and E of area 02/02/10 (4); length c.5m, width c.4m. Probably remnant of a larger mound.

02/02/10 (6) - Mound of tech.debris running roughly N-S and incorporated into a drystone wall which appear to run through it. Length of surviving mound c.11m, with surface slag scatter visible at S end and extending across rough ground E of mound. Quite low, c.1m max. height. Probable remnant of a much larger mound extending to half an acre.

02/02/10 (7) - Collapsed remains of a furnace identified adjacent to and immediately E of drystone wall at the foot of an acasia(neem) tree c.20m N-NE of 02/02/10 (6) and 30m NW of house standing on its own beside a new track; Barbed wire running along wall; newly cultivated land immediately to W where trees recently cut. Small area excavated, c.1m in length to reveal a rough arrangement of stones c.10cm-25cm in length. Small quantity of charcoal observed.

PM35:

02/02/10 (8) - Tech. debris observed scattered across a large area c.300mx200m, of rough ground and cotton, maize and vegetable fields. Believed to be the site of a former mound, but no visible traces of mound remain. Land much disturbed and levelled in S of area. Distinctive hemispherical cakes of furnace slag noticeably intact, and with a high degree of consistency in shape and size, were observed in two piles at the S edge of the area. Further of these slag cakes were observed in the fields.

PM36:

02/02/10 (9) - Roughly circular rock outcrop with iron ore on top, c.150m in circumference, c.200m N of area examined in 02/02/10 (8).

PM37:

03/02/10 (16) - Standing remains of a fort believed to be 1st century BC in date. Walls in situ up to 5m high along N and W sides and N end of E side, remaining as a low mound along S and E side; no wall structure visible along S side gap or entrance at centre of N wall. Enclosed area used for cultivation (turmeric and chilli noted). Approx. internal length 90m E-W; approx. width internal width 55m. Wall 1-1.5m thick, constructed of large mud bricks c.55cm long x 40cm high, with a thickness of 55-60cm. Bricks appear to have been made in situ. Walls 10-13 courses high. Repairs visible. Finds embedded in walls of tap slag (03/02/10 (16)), pottery rims and a frag. of bangle (possibly dark glass); these finds presumably of same date as wall construction. Slag scatter also observed on the ground. Abundance of slag both in walls and on ground. Possibly indicates presence of a former smelting site within fort area.

PM38:

03/02/10 (1) - Fragments of tech. debris embedded in mud brick walls of fort 03/02/10 (1). Scatter of slag also observed on ground within fort. Abundance of slag both in walls and on ground possibly indicates presence of a former smelting site within fort area.

03/02/10 (2) - Frags. of tech.debris and pottery observed in field of cotton adjacent to fort on E side. Remains of mud bricks from fort also noticed.

PM39:

03/02/10 (3) - Distributed mound of tech.debris, apparently a remnant of a much larger mound. Surviving mound c.10m long E-W, c.5m wide N-S and 0.5m in height. Original size probably 50m(E-W) x 40m(N-S). Acacia tree growing on mound; concrete electricity pole located towards E end where mound material trails off. Path crosses mound roughly N-S.

PM40:

03/02/10 (4) - Mound of tech.debris, modified and flattened but probably largely an original mound (although possibly just an area where farmers have mounded up the material). Sub. Rectangular in shape, c.40m N-S, c.30m E-W; raised 1-2m above adjoining fields. Flat top of mound cultivated with beans; teak trees also growing.

03/02/10 (7) - Mound of tech.debris c. 38m long E-W, 5m wide N-S; a little wider at end. Max height 1.5-2m.

PM41:

03/02/10 (5) - Scatter of pottery frags. In fields NE of 03/02/10 (4) and (7), SW of 03/02/10 (6). Many fallow fields observed in vicinity.

PM42:

03/02/10 (6) - Long, highly disturbed mound of tech. debris adjacent to a recent track to E. Mound length 60-70m running roughly NW-SE. Extent of slag scatter to SW of mound indicates original mound width of 50m, suggesting a sizable mound. Height c.2m.

PM43:

03/02/10 (8) - Two blacksmiths working areas adjacent to each other within village. A blacksmith was interviewed: int.ref.11.

PM44:

03/02/10 (9) - Substantial mound of tech.debris at S edge of village, with rice paddy immediately to S and SW mound c.80m long, c.45m wide and with a max height of 4m. Ground slopes slightly downwards to S of mound. Extensive surface scatter of slag and pottery around mound, with similar material observed within mud brick walls of a building adjacent to black smiths working area 03/02/10 (8).

03/02/10 (10) - Mound of tech. debris identified in the village N-NW of main mound area (03/02/10 (9)); this mound was not examined in detail.

PM45:

03/02/10 (11) - Extensive highly disturbed mound of tech.debris running roughly N-S. Long thin and fairly shallow; difficult to define its edges. Possible collapsed furnace remains identified on E side of mound by a tree stump. Mound possible 40mx40m originally. Adjacent to 03/02/10 (12)

03/02/10 (12) - Mound of tech.debris adjacent to and immediately NE of 03/02/10 (11). Two large trees growing on top of mound and a well at N end. Small temple on NE side of mound , believed to be 7th-8th century, consisting of large rocks with 2 rock carvings depicting the monkey god Hanuman. Mound possibly twice its present size originally. Extending to W and N.

PM46:

03/02/10 (13) - One of 2 prominent mounds c.40m apart of tech.debris. This record refers to the western mound. Steep sided; c.30m in length with a max width of c.20m. Max. height 4m at S end where the mound was almost conical in shape; only 1.5m at N end where mound disturbed by quarrying.

03/02/10 (14) - One of 2 prominent mounds, c.40m apart of tech.debris. This record refers to the eastern mound. Less conical in shape than 03/02/10 (13), with a flattish top and tapering towards NW end. Mound c.30m in length, max width c.20m; survives to a height of 2-2.5m

03/02/10 (15) - Mound of tech debris running N-S parallel to and adjacent to road; c.60m in length and surviving to a height of 1.5m. Steeper on its E side. Appears to be remnant of a larger mound destroyed by the road construction. Surface slag scatter visible on W side of road opposite mound, indicating probable former extent.

PM47:

05/02/10 (1) - Mound of tech.debris adjacent to road, heavily quarried on E side and partially covered in low trees and shrubs; fields of cotton and beans to N, W and S, levelled area of waste ground and piled rocks between mound and road. Mound c.15m long E-W, c.9m wide N-S surviving to a height of 2.5m. Overall impression is of an in situ site, though some indication from villagers that mound had been added to by farmers cleaning slag from fields.

PM48:

05/02/10 (2) - Mound of tech.debris c.10m long N-S and c.8m wide E-W surviving to a height of 2m. Probable remnant of a larger mound.

PM49:

05/02/10 (3) - Scatter of tech.debris observed in area of rough ground and cultivated plot close to village houses and adjacent to steeply sloping bank of culvert. Tech. debris appears to represent area of levelled slag on which village houses have been built. (canal/culvert 4m deep, 10m bank to bank; N bank more sheer than S bank)

05/02/10 (4) - Long narrow mound of tech.debris extensively disturbed by recent earth moving on its E side. Mound c.37m long N-S, c.2m wide E-W; not high and incorporated into field boundary at N and S ends. Abuts onto canal at S end. Appears to be remnant of larger mound.

PM50:

05/02/10 (5) - Much disturbed area of slag within village, where a blacksmith's working area (still in use) and adjacent house appear to have been built on the site of a former mound. A few meters along path to N of blacksmith's area a small mound of slag identified, apparently composed of material redeposited from main mound mixed with tile frags. and other modern material.

PM51:

05/02/10 (6) - Scattered remains of a mound of tech debris, consisting chiefly of a small thin mound running N-S long field boundary, with associated slag scatter in the vicinity.

PM52:

05/02/10 (7) - Mound of tech.debris running E-W along field boundary, with material tailing off at E end. Mound c.15m long, c.6m wide, surviving to a height of 2m. Mound encroached on by fields on all sides.

PM53:

06/02/10 (1) - Pottery fragments identified in a field bank.

PM54:

06/02/10 (2) - Steep mound of tech.debris in field corner, running roughly E-W, surviving to a height of c.2m and c.4m wide. Contains very little modern material mound partially covered with vegetation.

06/02/10 (3) - Disturbed low mound of tech.debris on field boundaries (corner of three fields) <2m high and c.4m in length. Field clearance material deposited on top.

06/02/10 (4) - Pottery fragments observed as a surface scatter in a highly disturbed, recently dug out area of field. Similar fragments observed in field bank. A cleaned section in the field bank revealed an upper horizon of slag and store mix, below which pottery fragments were seen within a layer of loamy material mixed with degraded stone. This lower layer possibly represent an occupation horizon.

PM55:

08/02/10 (1) - The SW half of a large oval mound of tech.debris measuring c.55m long by 20m wide in total. It is c.2m in height close to the road but up to 2.5m further away. The site is immediately surrounded by fields in various stages and forms of cultivation but all contain moderate densities of derived technological material visible on the surface. This half of the mound is characterised by crucible debris.

08/02/10 (2) - The NE half of a large oval mound of tech.debris measuring c.55m long by 20m wide in total. It is c.2m in height close to the road but up to 2.5m further away. The site is immediately surrounded by fields in various stages and forms of cultivation but all contain moderate densities of derived technological material visible on the surface. This half of the mound is characterised by smelting debris.

08/02/10 (3) - Possible road clearance material derived from 08/02/10 (1) and (2) forming a series of low unconsolidated mounds of varying shape and size (although mostly sub-circular and up to c.10mx10m in dimensions).

PM56:

08/02/10 (4) - Irregularly shaped mound of tech.debris bisected by the road. The N half measured c.25m by 25m. The S half measured c.45m long by c.25m wide. The road cutting presents 2 sections through the mound to be visible, exposing c.2m of deposits.

08/02/10 (5) - Sub-circular mound of tech.debris measuring c.25m across. It forms one of a large group of sites (that were not all recorded) heading NE into the forest.

08/02/10 (6) - Sub-circular mound of tech.debris. Forming one of a large group of sites (that were not all recorded) heading NE into the forest.

08/02/10 (7) - Only GPS recorded. It is a slag heap. Sub-circular mound of tech.debris. Forming one of a large group of sites (that were not all recorded) heading NE into the forest.

PM57:

08/02/10 (8) - Mound of tech.debris incorporated into a field boundary, c.40m long and up to 1m high. The site formed part of a terrace, with much lower cultivated land to the W and level ground with scatters of slag to the E.

PM58:

08/02/10 (9) - A field containing a dense surface scatter of tech.debris now utilised for cotton production, including two possible levelled mounds. This E part of the site is characterised by large quantities of crucibles, the W extent (08/02/10 (10)) is characterised by its lack of them.

08/02/10 (10) - A field containing a dense surface scatter of tech.debris now utilised for cotton production, including two possible levelled mounds. This W part of the site is characterised by lack of crucibles, the E extent (08/02/10 (9)) is characterised by their presence.

PM60:

09/02/10 (1) – Large ovate mound of tech.debris 3-4m high and c.20mx12m on the upper terrace of agricultural land, oriented N-S. To the SE c.5m there is a secondary deposit of material, separated by the road, consisting of a levelled out concentrated spread of tech.debris. Majority of debris consists of crucible fragments varying in size with infrequent furnace and tuyere material. Some roppey tap slag and dense furnace slag.

09/02/10 (2) – Large ovate mound of tech.debris measuring c.40mx30m and c.5-6m high. Disturbed by two residential structures on the top, flattening the summit. Possible continuation to the E (now occupied by residential buildings and a dirt trackway) with a slight depression visible.

09/02/10 (4) - Large mud brick wall containing huge quantities of tech.debris, primarily smelting slag although crucible remains were noted on the track/road nearby.

PM61:

09/02/10 (3) - Sub-circular slag heap c.40m in diameter, now largely disturbed and used as a rubbish dump.

PM62:

09/02/10 (5) - Old stone (possibly granite) temple/shrine to Sri Anjaneya located in agricultural land just outside of the village, surrounded by a spread of tech.debris over an area of about 100sq.m/2 fields. Material was primarily crucibles, although some tap slag and furnace remains present. The crucible frags. were particularly abundant in the E half of one field and within the adjacent, low field boundary.

PM63:

09/02/10 (6) - Levelled slag heap now scattered over several paddy fields over an area c.70x80m. Greater concentrations of technological debris on field boundaries and levelled slag heap at S end of scatter.

PM64:

09/02/10 (7) - Recently levelled mound of tech.debris, densely spread over a large field c.30x90m spread, bounded by a canal and dense vegetation on two sides. The material is large frags. of smelting waste.

PM65:

10/02/10 (1) - Large mound of tech.debris measuring c.30mx16m oriented N-S, with a height of c.4m. Seems mostly undisturbed except on S and W parts which have modern buildings. Majority of material comprises of crucibles of various sizes. Also some small fragments of green glassy slag and furnace slag. Very few fragments of tap slag noticed.

10/02/10 (2) - Small discreet mound of tech.debris measuring c.7-8m in dia. and 1.5m high. Bounded by a drystone wall to the S and W. The surrounding field contains a thick scatter of crucibles (greater concentration within 15m of mound) and slag possible field clearance mound, material does not seem consolidated.

PM66:

10/02/10 (3) - 'The traders house'-documented to be at least 200 years old. 2 storey wooden/timber and mud brick structure with central courtyard. It is c.4-5m high with a clay tiled roof. The SE corner is severely damaged, with only ruined walls remaining. The wood around the doorways are highly ornate with carvings. Various walls within the courtyard have niches for storage of goods and money.

PM67:

10/02/10 (4) - Scatter of tech. debris within a field c.28mx18m. The material is concentrated in the N where it forms part of a brick and drystone wall. Material is predominantly crucible fragments and green glassy slag. Some small fragments of furnace slag and very few pieces of tap slag.

PM68:

21/09/09 (4) - Crucible deposit exposed in pit dug for new concrete pillar. Dense deposit of crucible fragments - below surface undisturbed.

PM69:

11/02/10 (1) - A low poorly preserved mound of metallurgical waste. The mound is linear (c.6m long) and disturbed by a road (dirt track) on one side. It has large boulders piled on the top and forms part of rough wall of a modern habitation compound on the W side of the road. The remaining part of the heap is approximately 30cm high. It primarily consists of dense tap slag (2-5cm thick) with few ripples (low viscosity) on top surface, a considerable proportion of very rough and slightly porous furnace slag and a little furnace wall (some with parallel imprint lines). Jaikishan says that this heap was only levelled in past few years.

PM70:

11/02/10 (2) - A sparse scatter of metallurgical debris (smelting) in a cotton field. Reportedly there were slags heaps here around 15 years ago but have now been destroyed/removed (for road construction or filling wells?). The material primarily consists of tap slag with few ripples and c.2-4cm thick, few furnace slag fragments and very few furnace wall fragments. Pottery was also recorded.

11/02/10 (3) - Jaikishan says that there was another heap here about 15-20 years ago but there is no trace of it now. Jaikishan says that this was confirmed by local villagers. Pottery was found and recorded.

PM71:

11/02/10 (4) - Centre of village was a blacksmith's smithy belonging to Katta Rajaiah. This blacksmith was interviewed - refer to interview 14 for information. The floor level smithy was very basic and outdoors (uncovered). It consisted of a smithing hearth to the left of the smith, a square but elongated anvil in front of him and two largish sharpening stones to the right with a small bucket of water. The hearth consisted of a tallish, straight, thick clay wall (seemingly built in three large vertical slabs) on one side and a small depressed hole filled with charcoal in front of it with hand crank rotary bellows behind it. The bellows were about an arms-length of the smith. The furnace wall had a tuyere hole at the base with the bellows angled down slightly reaching the top of the charcoal on the other side. The anvil was imbedded into a wooden base (beam or tree truck) which was itself imbedded into the ground. The smith sat on a very small wooden rectangular stool (not more than 10cm tall). To his right was two largish smooth sharpening stones with significant wear and a water bucket. All of these were within arms-length of the smith occupying a central position. He also had a small wicket basket full of charcoal nearby.

PM72:

11/02/10 (5) - Remains of a metallurgical waste heap (smelting) on the N/NE slope of the rocky outcrop hillock. The waste survives to c.30m in length NW to SE (along the hill), c.12-15m wide and in some areas up to 1-2m deep. The remains lie on an exposed area of bare rock which forms like a flat granite platform. It seems like there may have been two heaps of material that were joined in the centre but hard to tell as the material had been subject to some disturbance and some of the remains were scattered around onto the granite shelf. The material primarily consisted of tap slag c.3-6cm thick, undulated undersides and rippley or agitated surfaces. Some rough textured furnace slag was present but majority of these were small and non-diagnostic scattered fragments. Furnace wall and some pottery were also recorded.

On the flat granite outcrops were some small oval/roundish holes which may have been used for processing ore (grinding or crushing the ore). One was excavated near the smelting waste heap and a small fragment of ore was found. The hole also had a reddish staining but this may just have been from the soil. Uncertain whether these were natural or man-made and if they were used for ore processing. Due to the fact that these small holes in the granite outcrops were seen further up the hill it is likely that they are natural.

Some ore was found on the hill but of very low grade.

PM73:

11/02/10 (6) - Remains of an irregular shaped metallurgical waste heap (smelting). It appears to be a tail end of a larger heap preserved by the presence of granite boulders and trees. Only the SW part of the heap survives as the rest was removed (bulldozed) according to Jaikishan in the past 5 years. The heaped remains survive to c.10-15m in length E to W and up to 8m wide N to S. The heap is c.50-70cm high (perhaps up to 1.5m in parts). A surface scatter of material was also observed around the mound extending up to 25m to the N. The majority of the material was rough, quite porous tap slag c.3cm thick with some furnace wall and tuyeres as well as some very magnetic banded magnetite ore.

PM74:

12/02/10 (1) - Large mounded slag heap c.75X50m. Large portion of heap removed in recent years (Google Earth image of 2008 shows deposit intact). Bulldozing and removal have exposed a 3-4m high section which shows deposit stratification. Section recorded on later visit (01/03/10). This heap is the core element of a much larger smelting and crucible steel complex.

12/02/10 (2) - In situ clay vessel exposed in top of section through slag heap (12/02/10 (1)). Upper part of vessel truncated at ground surface. Inverted sub-conical form c.0.3m max diameter. Coarse friable red fabric, no indication of vitrification. Possibly not associated with metallurgical processes. Base of vessel not present.

12/02/10 (6) - Remnants of large slag heap visible on 2008 Google Earth image but now most material removed and deposit survives in field boundaries. Original heap c.60x50m. Southern extent of deposit adjoins northern extent of 12/02/10 (1). Northernmost extent of Parasurampalli complex.

12/02/10 (7) - Slag heap partially cut by later road c.40x45m and 2m high. Maybe contiguous with 12/02/10 (1) and (6) but now separated by road, c.120m NW from core of complex at 12/02/10 (1).

12/02/10 (8) - Remnants of discrete slag heap largely destroyed by road construction. Original deposit survives on E side of road. 150m W-SW of core of Parasurampalli complex at 12/02/10 (1). Does not appear to be contiguous with other elements of complex.

12/02/10 (9) - Remnants of possible slag heap now largely removed, c. 200m SW of core of Parasurampalli complex at 12/02/10 (1).

12/02/10 (10) - Remnants of possible slag heap now removed, c.300m SW of core of complex at 12/02/10 (1).

PM75:

12/02/10 (3) - Levelled crucible waste heap c.30x50m. Reputedly levelled c. 25years ago to create cotton field. This location is southernmost extent of the Parasurampalli complex. Distance to northernmost point c.400m. Distance to core of complex at 12/02/10 (1) c.250m. Forms an arc of crucible waste heaps with 12/02/10 (4) and (5).

12/02/10 (4) - Undisturbed crucible waste heap c.30x45m and 1.5-2.0m high. Central heap of 150m arc of three crucible waste heaps (12/02/10 (3), (4) and (5)) on SE edge of Parasurampalli complex. 200m S-SE of core of complex at 12/02/10 (1).

12/02/10 (5) - Crucible waste heap encroached around periphery by cultivation. Now 25x10m and 1.5m high. Easternmost of arc of three crucible waste heaps (12/02/10 (3), (4) and (5)) on SE edge of larger smelting and crucible steel complex. Easternmost edge of Parasurampalli complex c.200m SE of core of complex at 12/02/10 (1).

PM76:

13/02/10 (1) - Remains of a disturbed metallurgical residue heap (smelting). The heap was mostly flattened and was roughly oval in shape occupying an area c.9x9m. The best preserved parts of the heap survived among tree roots on the NE side of this small parcel of land and amongst an area of boulders on the SE side. The material scatter spanned an area of c.30m E-W and c.20m N-S. In this area the soil colour seemed darker than the surrounding soil perhaps being indicative of the original size of the heap. The material primarily consisted of tap slag (some were very smooth), large furnace slag bases, furnace wall and tuyeres. Some of the material had been piled (secondary) into small heaps. A heap of slag was found in the centre of the scatter and a heap of furnace wall to the SW.

PM77:

13/02/10 (2) - Metallurgical waste (smelting) in paddy field bank boundary. The bank is linear running between two paddy fields with N-S alignment. The bank is c.45m long and it is raised to c.1.5m in height on the W field and c.0.75m on the E field. The material seems to have been mostly removed as there is very little scatter seen in the two adjacent fields on either side of the bank (maybe cleared and used to make boundary?). The material primarily consisted of smelting slag, tuyeres and some pottery was recorded. Material similar to location 13/02/10 (1).

13/02/10 (3) - Part of two heaped metallurgical waste (smelting) remains; (3) is the N heap and (4) is the S heap. The N heaped remains (3) were c.10m long and 9m at the widest and up to 1m in height bounded to the S by a field boundary. The heap was covered in shrub and some trees and there was an area on top where large fragments of slag could be seen. Looks like it may have been partially flattened and the two remaining mounds of material (3 and 4) may have been part of a larger heap measuring c.50m long and c.30m wide. A rectangular field now cuts part of the southern end of (3) and the eastern part of (4). According to Brian the slag morphology seemed a bit different to (1) and (2) being generally rougher.

13/02/10 (4 - Part of two heaped metallurgical waste (smelting) remains; (3) is the N heap and (4) is the S heap. The S heaped remains (4) seemed to be less preserved than (3) being incorporated into the field boundary to the E. It was c.14m in length, c.5-6m wide and up to 0.5m in height forming a linear type of deposit attached to the E field boundary. Looks like it may have been partially flattened and the two remaining mounds of material (3 and 4) may have been part of a larger heap measuring c.50m long and c.30m wide. A rectangular field now cuts part of the southern end of (3) and the eastern part of (4). According to Brian the slag morphology seemed a bit different to (1) and (2) being generally rougher.

PM78:

13/02/10 (5) - Abandoned village - according to Jaikishan abandoned recently in 1995 when the inhabitants moved out after flooding took place. Undergrowth as now taken over and the process of decay was accelerated by the planting of cotton in one compound. Walls still standing to roof height - construction consists of three courses of stone blocks (up to 40x25cm) at the base and then a brick wall above coated with cement.

PM79:

13/02/10 (6) - A metallurgical waste heap (smelting) which is part of a series of aligned waste heaps (or peaks in material dump) in the teak forest N of the village. Location (6) constitutes the southern-most heap. The six heaps (6-11) are aligned SW-NE spanning c.60m in length and c.20m wide and up to 2m in height. There is material also scattered in between the heaps. Material predominantly smelting slag and some furnace wall.

A second group c.40m N of these constitute of three/four heaps (12-14) aligned NW-SE spanning c.40m in length."

13/02/10 (7) - A metallurgical waste heap (smelting) which is part of a series of aligned waste heaps (or peaks in material dump) in the teak forest N of the village. Location (7) is c.5m NE from (6). The six heaps (6-11) are aligned SW-NE spanning c.60m in length and c.20m wide and up to 2m in height. There is material also scattered in between the heaps. Material predominantly smelting slag and some furnace wall.

13/02/10 (8) - A metallurgical waste heap (smelting) which is part of a series of aligned waste heaps (or peaks in material dump) in the teak forest N of the village. Location (8) is c.10m NE from (7). The six heaps (6-11) are aligned SW-NE spanning c.60m in length and c.20m wide and up to 2m in height. There is material also scattered in between the heaps. Material predominantly smelting slag and some furnace wall.

13/02/10 (9) - A metallurgical waste heap (smelting) which is part of a series of aligned waste heaps (or peaks in material dump) in the teak forest N of the village. Location (9) is a few metres E of (8). The six heaps (6-11) are aligned SW-NE spanning c.60m in length and c.20m wide and up to 2m in height. There is material also scattered in between the heaps. Material predominantly smelting slag and some furnace wall.

13/02/10 (10) - A metallurgical waste heap (smelting) which is part of a series of aligned waste heaps (or peaks in material dump) in the teak forest N of the village. Location (10) is c.10m NE of (9). The six heaps (6-11) are aligned SW-NE spanning c.60m in length and c.20m wide and up to 2m in height. There is material also scattered in between the heaps. Material predominantly smelting slag and some furnace wall.

13/02/10 (11) - A metallurgical waste heap (smelting) which is part of a series of aligned waste heaps (or peaks in material dump) in the teak forest N of the village. Location (11) is c.10m NE of (10). The six heaps (6-11) are aligned SW-NE spanning c.60m in length and c.20m wide and up to 2m in height. There is material also scattered in between the heaps. Material predominantly smelting slag and some furnace wall.

13/02/10 (12) - Remains of a heap part of the second group c.40m N of the most northern of the six heaps (11) forming the S group. Constitutes of three/four heaps (12-14) 10-15m apart aligned NW-SE spanning c.40m in length. All heaps circular/oval in plan and c.5-10m across. They appear to be loosely grouped around a central open, flattish area (perhaps ancient location of furnaces?). Location (12) is the western most heap.

13/02/10 (13) - Remains of a heap part of the second group c.40m N of the most northern of the six heaps (11) forming the S group. Constitutes of three/four heaps (12-14) 10-15m apart aligned NW-SE spanning c.40m in length. All heaps circular/oval in plan and c.5-10m across. They appear to be loosely grouped around a central open, flattish area (perhaps ancient location of furnaces?). Location (13) is the central heap.

13/02/10 (14) - Remains of a heap part of the second group c.40m N of the most northern of the six heaps (11) forming the S group. Constitutes of three/four heaps (12-14) 10-15m apart aligned NW-SE spanning c.40m in length. All heaps circular/oval in plan and c.5-10m across. They appear to be loosely grouped around a central open, flattish area (perhaps ancient location of furnaces?). Location (14) is the eastern most heap.

There is another possible heap c.10-20m S of (14) but no GPS taken."

13/02/10 (15) - In situ furnace remains found at the base (N) of slag heap (7). Furnace embedded in the lower slope of the heap and excavated on the 15/02/10 (plans in diary). Tap slag hole identified to the SW side of the furnace with a hollowed out channel (probable there was a lintel over the hole?). A large piece of smooth tap slag c.45cm long and c.16cm wide remained in position just outside the furnace opening. Furnace slag also present at the base of the main structure (50x30cm). Both tap and furnace slag removed for sampling. Furnace walls consisted of narrow degraded, roughly shaped granitic rocks with a clay lining on the interior. Original lining partially disintegrated and collapsed and the furnace may have been re-lined. Immediately to the N was what looked like a paved area c.60x45cm consisting of smoothed, flat stones. NW of this paved area was a long stone (60cm in length, 30cm high and 20cm width) that appeared to have been deliberately set upright.

PM80:

15/02/10 (1) - Undisturbed slag heap c.10x6m, and max 1m high. Part of cluster of similar slag heaps.

15/02/10 (2) - Two undisturbed adjoining slag dumps forming one irregular heap, c.30x40m and max 3m high.

15/02/10 (3) - Undisturbed slag heap, c.10x15m and 1.5m high. Smelting slag with high proportion of tap slag. Part of cluster of slag heaps in forest.

15/02/10 (4) - Remnants of in situ furnace. Semi-circular footprint of furnace of predom. clay with granitic stone elements, c.0.6-0.7m diameter. Lies between slag heaps 15/02/10 (2) and (3) and adjacent to furnace feature 15/02/10 (5).

15/02/10 (5) - Remnants of in situ furnace. Semi-circular footprint in clay, c.0.6m diameter, with associated stone elements. Lies adjacent to 15/02/10 (4) and between slag heaps 15/02/10 (2) and (3).

PM81:

15/02/10 (6) - Scatter of mixed material in ploughed field adjoining road. Includes microlithic flaked tools and cores on quartz and chert, pottery and occasional slag.

PM82:

16/02/10 (1) - Remnants of very large smelting slag heap, c.35m long and c.1.5m high to the W and c.4m high to the E. Disturbed probably due to road construction but part of heap survives. Village blacksmiths said ore was brought from Shekella by bullock cart (see interview records).

PM83:

16/02/10 (2) - Remnants of slag heap c.0.7m high and c.35m wide; encroached on N side by house constructions and on S side by agriculture.

16/02/10 (3) - Remain of small tech. debris heap but mainly scatter of slag in cotton fields with concentrated deposit in field boundaries, possibly the result of field clearance.

PM84:

16/02/10 (4) - Scatter of smelting slag in cultivated fields with material concentrated in field boundaries. Includes some crucible fragments. One piece of magnetic ore collected.

16/02/10 (5) - Small slag heap surviving to 1m high in area of cultivation forming part of a field boundary. Some abraded crucible fragments observed.

PM85:

16/02/10 (6) - Extensive scatter of slag in cotton fields (at least 40m spread) with concentrated area marking position of original heap. Scatter includes pottery and white sandstone building material probably derived from collapsed structure (16/02/10 (7)).

PM86:

16/02/10 (7) - 3m high mound with abundance of white sandstone fragments indicating collapsed structure. Reputedly possibly an early Buddhist structure of 1st-5th century AD.

PM87:

17/02/10 (1) - Scatter of slag and crucible waste in cotton field. Slag heaps reputedly removed 15-20 years ago. Material very abraded. Also considerable amounts of pottery indicating possible settlement. Slag includes smithing slag

PM88:

17/02/10 (2) - Part surviving slag heap, c.18x8m oriented E-W, and max 1.5m high, with crucible waste also. Encroached on by paddy and cotton fields. Site revisited in June 2011 and soils samples collected as background data for OSL/TL dating.

17/02/10 (3) - Remnants of slag heap with crucible waste surviving as enlarged field banks standing 1m high and 1.5m wide. Indicates original heap c.25x25m.

PM89:

17/02/10 (4) - Site of former village settlement with scattered material including some slag. Also includes cut and decorated stone elements of a possible temple structure, reputedly stylistically datable to 6th-7th century AD.

PM90:

17/02/10 (5) - Material washed and tumbled from steep river bank from periphery of former village settlement. Includes cut and decorated stone elements of possible 6th-7th century AD temple structure. Finds include smithing slag.

17/02/10 (6) - Scattered slag and pottery in cotton field associated with former settlement and possible 6th-7th century temple structure.

PM91:

18/02/10 (1) - Disturbed deposit of smelting slag with some reported crucible waste. Deposit forms visible low mound buried below road and school construction. The newly built constructions have brought in new material but abraded slag, old brick and pot sherds are found in surrounding paddy fields and road bank. Extends over c.40m length of road but this may be spread from levelling. Very few crucible fragments observed but reputedly samples have been observed and collected. Location first visited 20/09/09 (1).

18/02/10 (2) - Remnants of smelting slag heap now encroached by paddy cultivation.

PM92:

18/02/10 (3) - Surviving slag heap c.45x25m, oriented N-S, and max 1.5m high, forming long low mound.

PM93:

18/02/10 (4) - Remnant of smelting slag heap c.40x20m and max 1.5m high. Partially cleared to create cultivation fields.

PM94:

18/02/10 (5) - Extensive scatter of smelting slag adjoining road. Material visible in road ditch. Distribution of material suggests possible ore processing area distinct from smelting area.

PM95:

18/02/10 (6) - Deposit of smelting slag indicating possible slag heap now levelled by road construction and for cultivation. Actively being removed at time of recording.

PM96:

18/02/10 (7) - Remnants of smelting slag heap now levelled and material removed, possibly for adjacent road construction.

PM97:

19/02/10 (1) - Traces of metallurgical waste (smelting) scattered around paddy field cultivation next to a water tank (Jaikishan says it is reasonably modern?). Material appears to have been mostly removed for cultivation. Scatter predominantly of medium to large cakes of tap slag with very roppey surfaces, some furnace slag and furnace wall. Associated with 19/02/10 (2) which has more remains in one of the paddy field banks.

PM98:

19/02/10 (2) - Metallurgical waste in paddy field boundary bank which looks to have been disturbed. Primarily the same roppey tap slag as (1) and not dense enough (quantity) to be classed as a separate site.

PM99:

19/02/10 (3) - Remains of a large metallurgical waste heap (smelting) with a dirt track running through it. The W side remains mostly undisturbed with vegetation and trees growing but the E side had recently been bulldozed/flattened to leave way for agricultural fields (sometime since first visit 20/09/09 (3)). The heap had been c.30-40m across and vaguely circular in plan but the E side has been removed leaving a scatter of material in the field and a large linear heap of secondary material along the length of the track. The W side survives to a height of c.1.5m. The material predominantly consisted of roppey tap slag, rough furnace slag, tuyeres and furnace wall.

PM100:

19/02/10 (4) - Largely undisturbed metallurgical uneven waste heap (smelting) vaguely circular in plan. The heap is c.25-30m across and up to 2m in height. Material primarily tap slag, furnace slag, large frags of furnace wall (with vertical striations) and tuyeres.

19/02/10 (5) - Large metallurgical waste (smelting) heap which has been partially disturbed/flattened on its SE end. Surviving heaped remains c.50m long and c.40m wide but the slag may have extended further on the SE end which is now occupied by agricultural fields (may originally have been up to 90m long). Scatter of material in the SE end field. Heap surviving 2-3m high (from photos). Material primarily tap slag, furnace slag bases, furnace wall and tuyeres.

19/02/10 (6) - One relatively undisturbed (apart from road going through it) oval shaped metallurgical waste (smelting) heap c.50-60m long N-S and c.30m wide E-W. It is up to 3m in height with the highest point on the E side of road. Since road goes through the waste heap there is material on both sides of the road but the majority seems to be on the E side of the road. Material predominantly roppey tap slag, rough furnace slag and furnace wall. (first visit 20/09/09 (4)).

PM101:

21/02/10 (1) - A backyard area S edge of village with adjacent fields to the S. Very small traces of a smelting slag heap now mostly gone. Area seems to have been reduced in level perhaps for use as road ballast. (Jaikishan says that there was an extensive scatter of both smelting and crucible debris here 5 years ago).

PM102:

21/02/10 (2) - Houses with mud brick walls on the small track from (1) to (3) showing imbedded remains of smelting and crucible waste but mainly tap slag.

21/02/10 (3) - Behind (N of) houses is a small side lane with open shrubby ground with small rocky outcrops next to it. Some (not much) remains of smelting and crucible waste which may have once been a heap. Area is c.30x30m but there is not enough diary data to say more. Photos suggest that it may have been sparse surface scatter.

21/02/10 (4) - Traces of smelting (maybe other waste too but mainly tap slag) debris in mud brick walls of houses and some on the ground.

21/02/10 (5) - Mixed smelting and crucible slag waste (including green glassy slag) in a mud brick house wall. No more information available. Need to amalgamate this location with (6) as they appear to be the same in Brian's descriptions.

21/02/10 (6) - Small lane adjacent to mud brick house wall (5) with smelting and crucible debris. The lane appears to go over the heap preserving a flattened profile revealing mainly crucible waste.

PM103:

21/02/10 (7) - Remains of mainly crucible waste heap with some slag to the NW of drystone tower (8 - ruinous). No more information in Brian's diary.

21/02/10 (8) - Ruinous drystone tower (fort?) with secondary mud brick capping wall and containing a lot of crucible waste in it. Tower stands on a rocky outcrop overlooking main part of village especially S and W.

PM104:

21/02/10 (9) - Levelled remains of a smelting slag heap with a low mound in its centre.

PM105:

21/02/10 (10) - Megalithic burial site (Jaikishan's land).

PM106:

22/02/10 (1) - A large very disturbed and mainly flattened smelting and crucible debris heap. Appears to have been primarily crucible waste. The site is dominated by a modern (about 10 year old) water tower tank with enclosure which appears to have been built on the main metallurgical waste heap. Behind this enclosure (to the E) there was a small expanse of flat bare land surrounded by modern buildings which had surface scatter of crucible fragments. At the E end of the open area (c.30m E of the water tower enclosure) there was a greater concentration of metallurgical debris which was heaped near an enclosure (forming boundary of open land expanse). The heap was c.1m in height and 5-10m in width. There was also a noticeable amount of smelting tap slag on the E side of the site. The heap and scatter remains were c.40-50m long and up to 30m wide. First visited 21/09/09 (1).

PM107:

22/02/10 (2) - The name of the blacksmith was Rajeshwara Mattela. The smith was interviewed so please refer to the interview book.

There was an outdoor smithy in a courtyard covered by a corrugated iron roof. The smithing hearth was built against a wall. It was rectangular and the hearth walls were made of bricks cemented with clay. If facing the wall the modern hand cranking rotary bellow was situated on the left hand side of the hearth with the hearth opening at the front. The metal tuyere was placed through a hole at the base of the hearth wall slightly facing downwards as the exterior ground surface appears to have been elevated compared to the interior of the hearth. The square (c.10cm wide) but tallish (c.20cm) anvil was placed very close (30-40cm) from the hearth opening and slightly raised on a wooden beam. The place where the smith would sit was evident from a rag placed on the left side of the hearth in between the anvil and the bellow meaning that one smith could operate the bellows and smith without moving. The sitting area is raised and is an extension of the raised ground around the left side of the hearth. The surface in front of the hearth opening is lower meaning that the smith would be sitting on a ledge. On the left hand side of the hearth there is also a carved hole in a large stone block where there is water which would have been used for quenching. If the smith is sitting at the hearth then he would have had access to the bellows on his left, the anvil in front and the quenching hole on his right.

There was a second indoor smithy arranged in a very similar way. This one was not built against a wall and the walls of the hearth were well smoothed clay. It appeared to be more modern and the area around it was clean. The rock used for quenching was replaced with a small metal bucket and the sitting rag was replaced by a very small rectangular wooden stool (c.5cm tall). The tools of the trade were placed around the metal bucket for easy access when smithing. The rest was the same as the outside smithy. The hearth wall where the bellows were situated was a lot thicker and longer than the adjacent wall.

PM108:

22/02/10 (3) - Remains of a levelled slag heap with metallurgical material just below the surface. Some furnace wall was found but primarily consisted of tap and furnace slag. The tap slag had ripples and most fragments were between 1-3cm thick. Looked like a smelting deposit and the scatter was c.40m N-S and c.25m W-E.

22/02/10 (4) - A large surface scatter of metallurgical debris c.110m S of (3). The scatter was c.100m N-S and c.30-40m W-E in size with a slight rise in the ground level in the centre of the scatter (GPS 895). This rise seems to be close to a wall running W-E which may have been the back wall of the mission enclosing a yard. On the W edge of this open area is a large cross mounted on a platform suggesting that the area may have been a meeting place. Brian thinks that the original metallurgical waste heap may have been flattened to build the missionary. According to the locals the Christian missionary was about 200 years old. The material seemed to be smelting waste with mainly tap slag and some furnace slag. The tap slag is quite dense with less ripples (but still some) than in location (3), quite homogenous and c.3-4cm thick.

PM109:

22/02/10 (5) - A Mammaya temple dedicated to this deity of iron and steel. A small rectangular concrete building not more than 5m in length and 3m wide with whitewashed exterior walls. Both Mammaya and Vishwakarma idols were found in the same shrine. The chief priest was Mattala Pedda Ganguru. This temple was surrounded by crucible deposits (no more information given in diaries).

PM110:

23/02/10 (1) - Levelled slag heap noticeable by the heavy scatter of metallurgical material. Metallurgical waste found scattered across a number of small fields. The scattered material primarily consisted of small broken fragments of moderately dense tap slag with clear surface ripples. Towards the centre of the spread there was a small mound (or raised ground) where there was a higher concentration of residue. This included furnace slag bases and a larger proportion of moderately sized tap slag fragments and furnace wall. The material seemed to spread c.20m in all directions (40x40m).

PM111:

23/02/10 (2) - Scatter of metallurgical residue in ploughsoil of chilli plantation field. The greater concentration of which was c.100m NW of village. Similar material to that of 23/02/10 (1). Mainly shallow tap slag fragments and amorphous fragments of relatively dense furnace slag. Some furnace wall and tuyere fragments also noticed. Not much evidence of primary slag mound and Brian thinks it may have been removed by the building of a very large well found on the S side of the scatter.

PM112:

23/02/10 (3) - Small smelting slag heap (c.10-15m) associated with 23/02/10 (4) to (7) which are all very close (spaced c.5m from one another) aligned N-S (overall length of complex c.100m long). This is the southern-most heap. Probable evidence for more levelled heaps a few tens of metres to the W where the land appears to have been cleared. Brian thinks they may have been flattened to provide ballast for road construction.

23/02/10 (4) - Small smelting slag heap (c.10-15m) associated with locations 23/02/10 (3), (5) to (7) which are all very close (spaced c.5m from one another) aligned N-S (overall length of complex c.100m long). Probable evidence for more levelled heaps a few tens of metres to the W where the land appears to have been cleared. Brian thinks they may have been flattened to provide ballast for road construction.

23/02/10 (5) - Small smelting slag heap (c.10-15m) associated with locations 23/02/10 (3), (4), (6) and (7) which are all very close (spaced c.5m from one another) aligned N-S (overall length of complex c.100m long). Probable evidence for more levelled heaps a few tens of metres to the W where the land appears to have been cleared. Brian thinks they may have been flattened to provide ballast for road construction.

23/02/10 (6) - Small smelting slag heap (c.10-15m) associated with locations 23/02/10 (3) to (5) and (7) which are all very close (spaced c.5m from one another) aligned N-S (overall length of complex c.100m long). Probable evidence for more levelled heaps a few tens of metres to the W where the land appears to have been cleared. Brian thinks they may have been flattened to provide ballast for road construction.

23/02/10 (7) - Small smelting slag heap (c.10-15m) associated with locations 23/02/10 (3) to (6) which are all very close (spaced c.5m from one another) aligned N-S (overall length of complex c.100m long). Most northern heap. Probable evidence for more levelled heaps a few tens of metres to the W where the land appears to have been cleared. Brian thinks they may have been flattened to provide ballast for road construction.

PM113:

23/02/10 (8) - Remains of a smelting waste heap which has been bisected by the eastern village road. Very disturbed primarily slag remains. These survive better at the southern extent of the scatter because of its location close to or within a granite outcrop. The rest of the heap may have been removed and levelled for road construction (scatter spread at least 40m wide). Associated with location (9) c.30m SW which may be a continuation of this disturbed smelting waste heap. Both locations have similar material essentially comprising of large, quite dense purple and ropey tap slag. This slag appears to have either plano or convex bases. Very little refractory material or recognisable furnace slag.

23/02/10 (9) - Possible continuation of 23/02/10 (8) remains on opposite side of road c.30m SW. Jaikishan says that they were part of larger slag heap. Material there is similar to location (8) and scattered at least 20m along village road.

23/02/10 (10) - Partially surviving heap of metallurgical waste consisting of smelting debris. Heap surviving to c.1-1.2m in height but heavily disturbed by modern habitations (farmyard). Appears to have been cut away for habitation to S and E. Surrounding scattered remains suggest that the heap was probably larger than at present, perhaps around 30m across. Material similar to locations 23/02/10 (8) and (9) mainly consisting of dense, purple and ropey tap slag with convex bases. Top surfaces smooth and undulated undersides. There is also evidence that in this location ore was extracted or processed (no more info).

PM114:

23/02/10 (11) - The area is a raised compared to the village forming a small hill. Probable ore source as ores were found which may have been roasted. There was some slag scattered in the vicinity but may have been brought in as road ballast when the road was constructed perhaps from location (12).

PM115:

23/02/10 (12) - Scatter/spread of metallurgical waste in a field 10m N of road. The probable heap was heavily disturbed and levelled (mostly removed) perhaps for use as ballast in the nearby road construction. The major concentration of material was adjacent to the small road and spread over c.15-20m around a small group of large granite boulders. The material mainly consisted of ropey, purple tap slag with a similar size and density as the material from 23/02/10 (10).

PM116:

24/02/10 (1) - Heavy scatter of metallurgical waste in field bounded by main road on E side. Probable remains of smelting debris heap now flattened/levelled either for road construction or agriculture c.40m E-W and c.30m N-S in size. The remains primarily consist of tap and furnace slag with few tuyere and furnace wall fragments. A possible fragment of bloom was also recorded.

PM117:

24/02/10 (2) - Light scatter of metallurgical debris, probably location of a smelting waste heap. Now levelled and material removed to below ground level. Material consisted of mainly tap slag but also some furnace slag and furnace wall.

PM118:

24/02/10 (3) - Smelting waste heap on edge/boundary of paddy cultivation fields. Approximately half of the heap removed to leave room for rice/paddy cultivation (very small field). The heap survives c.25m across and up to 1m in height. The western part of it survives to nearly 1.5m in height. Slag, tuyeres, furnace wall, bloom fragments, pottery, flint and iron metal implements (including a pair of corroded pliers) were recorded.

Jaikishan says that there were around 7 heaps in the vicinity (N of location between here and village) that he saw about 4 years ago. It would seem that they were all removed for road ballast and to build up the garden of a new house nearby. There is a range of low hills c.2km E which may have been a likely source for ore collection."

24/02/10 (4) - Heavy metallurgical residue scatter (smelting) forming imprint of a now levelled slag heap c.20m each way. Primarily consisting of slag with tuyere and furnace wall fragments. There is a nearby heaped mound to SE which comprises of redeposited remains of both slag and subsoil scooped up from adjacent field to the E.

PM119:

25/02/10 (1) - Remains of a metallurgical waste heap mostly levelled on N side of main road. The material primarily consisted of crucible fragments and smelting slag but also some tuyere and furnace wall fragments as well as green glassy slag and iron fragments. Pottery was also recorded. The partial remains of a heap was visible in a natural dip in the ground surface on the S part of the scatter. The northern extent of the scatter seemed to have mainly smelting waste but the southern part (closest to road) had a large proportion of crucible waste. A ditch next to the road (following its length) seemed to cut through the heap of metallurgical residue. A hill c.500m S which may have been possible ore source.

PM120:

25/02/10 (2) - Remains of a mostly flattened metallurgical residue heap (smelting). Located behind a modern house with a byre built on a low flattened mound of smelting waste. On the southern edge of the location (on field boundary) a small part of the heap survives to c.1.5m in height. Brian estimates the extent of the residue to be c.50m N-S and c.35-40m E-W based on the slight ground elevation. Material mainly consisting of smelting slag, furnace wall and a few possible iron fragments.

25/02/10 (3) - Traces of metallurgical waste in small field on E edge of village. Remains of a smelting residue heap now levelled or removed. Most material concentrated on a bank forming the E field boundary. Material is mainly smelting slag, furnace wall and some iron bloom fragments. Pottery also recorded. Brian estimates the original heap size c.35x30m.

25/02/10 (4) - Remains of a metallurgical (smelting) waste heap mostly levelled but survives up to 1.5m high on its most eastern edge bounded by a small track. Material was mainly smelting slag, furnace wall and some possible iron bloom fragments. Pottery also recorded. Brian believed that the heap must have been circular c.30m across. A hill c.200m E which may be possible ore source.

PM121:

25/02/10 (5) - Small low hill c.50m across and c.4m high showing signs of quarrying. Several possible tips of quarrying spoil seen. Some tap slag was also observed but in small quantity (brought in?). No ore seen so uncertain whether a possible ore source or other quarrying activities undertaken.

PM122:

25/02/10 (6) - A small hill (c.60-100m across) at the N edge of the village that could be a potential ore source. On the hill good quality banded magnetite ore was observed. The surface of the hill appears to have been quarried but these look recent and it is uncertain (hard to make out) if there was any older mining activities there.

PM123:

25/02/10 (7) - Scattered remains of a metallurgical waste (smelting) slag heap now fully levelled. A scattering of mainly tap slag now present suggesting a former smelting waste heap which has now been levelled to leave room for the school presently occupying the site. Brian thinks that the heap may have been up to 40m across.

PM124:

25/02/10 (8) - Remains of a levelled metallurgical waste heap in between (N of) the village road going SW-NE and a modern house. This road and a small lane next to the house forms the boundaries of the material scatter. Material primarily smelting slag with some tuyere and furnace wall fragments. Brian thinks that the slag may have been levelled and removed to be used as ballast for the road.

PM125:

26/02/10 (1) - Dense scatter of metallurgical waste covered by a thin layer of compacted dirt/mud. Probably remains of the lowermost part of a smelting waste heap. Current site occupied by a modern house, a byre and a mud brick house. A hill is situated c.60-90m W. Material was predominantly smelting slag, tuyeres and furnace wall. Pottery was also recorded.

PM126:

26/02/10 (2) - Mud brick wall with slag embedded in it and some on the ground.

PM127:

26/02/10 (3) - Dense scatter of metallurgical waste (smelting) over an area of c.100m NW-SE and c.70m SW-NE. Material predominantly furnace slag and some rough tap slag as well as some furnace wall and tuyeres. Pottery was also recorded.

According to a local lady it was a long high mound c.3m high consisting of two (sub) heaps and that they were levelled (not removed) c.15 years ago. She added that there was a huge amount of charcoal dust when they were disturbed. Tuyeres (round pipes - furnaces?) c.50cm wide were also found. From the discussion it seemed as though mud brick furnaces may have existed. The village she said had been much bigger but had shrunk in modern times.

26/02/10 (4) - A small part of heap surviving at one end of 26/02/10 (3). Predominantly smelting slag and furnace wall. Amalgamate with 26/02/10 (3).

PM128:

26/02/10 (5) - Scatter of metallurgical waste (mainly smelting) in a field. Probable evidence of smelting activity and a levelled slag heap. The material seems to concentrate in the middle of the scatter around a small hillock. Predom. tap slag and furnace slag bases are found in this location but some tuyeres and furnace wall material also present. Pottery was also recorded. It is directly adjacent to location 26/02/10 (6) which has a greater concentration of crucible remains. These locations are in the same field and consist of one large scatter but there is a greater concentrations of smelting waste to the W (5) and greater concentrations of crucible waste (although still predominantly smelting) to the E (6). Scatter c.50-60m across. Some large material was collected from the dry stone walls surrounding the site (field boundaries) including a furnace base.

c.200m S is a large (ore) hillock and may have been a potential ore source. This hill is part of a long ridge of hillocks going SW-NE.

26/02/10 (6) - Part of same large scatter of metallurgical waste as 26/02/10 (5). This location is the E part of this scatter where larger concentrations of crucible waste was observed. Along with the predominant smelting slag, crucibles and tuyeres were also present in this area. Scatter c.50-60m across (including (5)). Some large material was collected from the dry stone walls surrounding the site (field boundaries) including a furnace base.

c.200m S is a large (ore) hillock and may have been a potential ore source. This hill is part of a long ridge of hillocks going SW-NE.

PM129:

26/02/10 (7) - A long metallurgical waste heap on eastern edge (boundary) of mango plantation. The surviving heaped remains survive to a low height (?) and appear to be over 100m in length but disturbed by the present mango plantation which occupies the site. The scatter of material spreads to nearby fields. The material was predominantly small fragments of tendril (fine rippley surface) tap slag with some furnace wall and tuyeres. Iron ore deposits found to the S close to the large hillock ridge.

PM130:

26/02/10 (8) - Dense scatter of metallurgical material (smelting) in northern part of new mango plantation at the S base of a small rocky outcrop hillock. The scatter spreads to a small triangular field N of mango plantation between it and the hillock. Material predominantly tap slag, furnace wall and tuyeres. Pottery was also recorded. Tap slag is mainly small dense, roppey in nature. There is a drain ditch (recent) dug at the base of the hillock N of the scatter.

PM131:

27/02/10 (1) - Mud brick building wall with embedded fragments of slag, banded magnetite ore, pottery and possible fragments of iron. The ground also had some remains of metallurgical waste. The area had a slight rise possibly suggesting that this is where the former smelting waste heap had been. Not much now remains of it except the sparse scatter on the ground and in the wall. It was likely levelled to make way for this side of the village (may have been an extension of original village?).

27/02/10 (2) - Rough drystone wall with a large furnace wall fragment in it and fragments of tap and furnace slag. Probable smelting site now built over.

PM132:

27/02/10 (3) - Remains of a disturbed metallurgical waste heap. The material had been levelled and mainly consisted of slag and furnace wall fragments. Pottery was also recorded. An old hill fort with crumbling mud brick walls 27/02/10 (5) c.120m W.

27/02/10 (4) - Remains of a small metallurgical waste heap (smelting) primarily consisting of smelting slag, furnace wall and tuyeres.

PM133:

27/02/10 (5) - Small hillfort with crumbled mud brick walls (traces of) around hill top of rocky outcrop. Little fragments of slag, furnace wall and possible iron found on the surface (probable grog from the crumbled mud brick walls). Pottery also recorded.

PM134:

27/02/10 (6) - Remains of a large metallurgical debris heap (smelting) spread over two fields. Location (6) represents the S part of the scatter (S field) while location (7) is the N part (N field). The remains are c.60m N-S and c.40m W-E and according to Jai it was up to 3m in height only four years ago. The S part of the remains (6) appear to have been removed very recently while the other N part (7) was probably removed a while back. Material predominantly smelting slag, tuyeres and furnace wall. Pottery was also recorded. The centre of the scatter appears to be on the boundary between the two fields (GPS 939).

27/02/10 (7) - N part of heap - same as 27/02/10 (6).

PM135:

19/09/09 (6) - Scatter of metallurgical debris on both sides of a main track (non-tarmacked road). Location is disturbed and a former debris heap appears to have been flattened for road construction. Extent is unclear but material scatter on both sides of track. Material includes dense, heavy cakes of tap slag.

PM136:

19/09/09 (7) - Exposed deposit of banded magnetite quartzite at top of low hillock. Low scrubby vegetation hides surface but area looks heavily used. No obvious signs of tool marks or surface exploitation.

PM137:

19/09/09 (9) - Scatter of mainly tap slag across a large area. Very disturbed.

PM138:

19/09/09 (10) - Site of small temple with Nauda statue on the N bank (bund) of the water tank. The outer rampart of the village also appears to form the bund of the tank.

PM139:

20/09/09 (3) - Smith's house whose family descends from smelters. Family here remember smelting saying that production stopped in 1920's but older men say last smelt occurred c.1950. Slag scatters around houses and in other parts of the village (could have been built on slag mounds?). Mostly tap slag with big dense furnace bottoms and some refractory (tuyeres).

Appendix B – Assemblage Quantification by Weight

Appendix B.1 – Tap Slag and Smithing Slag by Site

This appendix presents the quantity in weight (g) of each tap and smithing slag sub-type from each site.

	Tap Slag					Smithing Slag		
SITE	TS1	TS1.1	TS1.2	TS2	TS3	SS1	SS2	SS3
PM1								
PM2								
PM3	4706				3030			
PM4	460							
PM5								
PM6								
PM7								
PM8	7569				1380			
PM9	4418							
PM10	4208			240				
PM11	2850							
PM12								
PM13								
PM14	5520	700	1340					
PM15								
PM16								
PM17								
PM18		5030		7330				
PM19	2388	3190						
PM20		960						
PM21	601							
PM22	1207	1320						
PM23								
PM24	137	2010		5251				
PM26	1130				780			
PM27	570			4310	230			
PM28								
PM29		850	890					
PM30	2330	1450			1010		682	
PM25								
PM31			2440					
PM32								
PM33								
PM34	4516	1090		1208				

	Tap Slag					Smithing Slag		
SITE	**TS1**	**TS1.1**	**TS1.2**	**TS2**	**TS3**	**SS1**	**SS2**	**SS3**
PM35	912				213	110	80	160
PM36								
PM37								
PM38	816	1710				1802		
PM39		1420	4580	565				
PM40		1390	1010	400				
PM41								
PM42	1463	680				240		
PM43								
PM44	1326	4390	2085					
PM45	3703	2690						
PM46	11889	9770	1440		220	230		200
PM47	13880							
PM48	7807	1140						
PM49	2814	640						20
PM50	1950					982		
PM51	7921							
PM52	1530	940						
PM53								
PM54	210	3141						
PM55	1490			576				50
PM56				3575				20
PM57								
PM58	840	961		12997	710		110	
PM59	1174							
PM60	101			1933				
PM61								
PM62				3730		193		
PM63					1140			
PM64	2024	610						
PM65	40			490				
PM66								
PM67	142							
PM68								
PM69	350							
PM70	790	850						
PM71								
PM72	2797		1339					
PM73	2190							
PM74	3379		1070	2477	2245		1185	28
PM75						870	175	
PM76	13906				510			
PM77	1370							
PM78								

	Tap Slag					Smithing Slag		
SITE	**TS1**	**TS1.1**	**TS1.2**	**TS2**	**TS3**	**SS1**	**SS2**	**SS3**
PM79	24504	2330		290				
PM80	7058							
PM81								
PM82	4850	572		160				
PM83	240			1084				
PM84	797	1087						
PM85	1391	390						
PM86								
PM87	580	2370				2260	100	
PM88	6811		960					
PM89		338						
PM90						3812		
PM91	4660		2739					
PM92				2640				
PM93	930							40
PM94	1260							
PM95				1401				
PM96	860							
PM97	1270			6709	704			
PM98				4080				
PM99	1395	390		2340				
PM100	14067	2580		750				
PM101	70	1040				524	31	
PM102	2280	210					100	
PM103		1030						
PM104						312	363	
PM105								
PM106	3320	460		2318				
PM107								
PM108	3430		1910	1470				
PM109								
PM110	1213							
PM111		650		2802				
PM112	6500	990		2700	120			
PM113	18426			490				
PM114	6400							
PM115	2638							
PM116	4798		1430	1040				
PM117	2613						50	
PM118	750	1410		863				
PM119	1450					153		
PM120	855						156	
PM121	1270							
PM122								

	Tap Slag					Smithing Slag		
SITE	**TS1**	**TS1.1**	**TS1.2**	**TS2**	**TS3**	**SS1**	**SS2**	**SS3**
PM123	2328	1290						
PM124	290			170				
PM125	6170							
PM126								
PM127	971	3160						
PM128	1562	1630						
PM129	1370				1740			
PM130	1454							
PM131	300							
PM132	2640		1350		848			
PM133								
PM134	1400	1189	817	6569		168		
PM135	2060							
PM136								
PM137	490		530					
PM138								
PM139	600							
TOTAL	277745	70048	25930	82958	14880	11656	3032	518
No. of sites	85	42	16	32	15	13	11	7

Appendix B.2 – Furnace Slag by Site

This appendix presents the quantity in weight (g) of each furnace slag sub-type from each site.

	Furnace Slag															
SITE	**FS1**	**FS1.1**	**FS1.2**	**FS1.3**	**FS1.4**	**FS1.5**	**FS1.6**	**FS2**	**FS2.1**	**FS3**	**FS4**	**FS5**	**FS5.1**	**FS5.2**	**FS6**	**FSND**
PM1																
PM2																
PM3									26108			5204				
PM4																
PM5																
PM6																
PM7																
PM8			12240							200		2437				
PM9	4830							360		6430		1859				
PM10									1220			3964				
PM11										960						
PM12																
PM13																
PM14															500	
PM15																
PM16																
PM17																
PM18	2490							900	837			680				
PM19	2220														1203	
PM20										784			1770			
PM21	1700											3060				340
PM22	9340		3880													

	Furnace Slag															
SITE	**FS1**	**FS1.1**	**FS1.2**	**FS1.3**	**FS1.4**	**FS1.5**	**FS1.6**	**FS2**	**FS2.1**	**FS3**	**FS4**	**FS5**	**FS5.1**	**FS5.2**	**FS6**	**FSND**
PM23																
PM24								2450		2200			4040	1280		
PM26			3150								350		430			
PM27			10310								240		370			
PM28				2423								640	2260			
PM29																
PM30												1650			4390	
PM25																
PM31				23140				480								1520
PM32																
PM33																
PM34			12690					1090	1860	550						
PM35						9070								280		
PM36																
PM37																
PM38	1160									640						
PM39								1220	570			2040				
PM40		3850										1250				
PM41																
PM42	960								725			560				
PM43																
PM44									1532				1090			
PM45												4738	390			
PM46	2870		12430					230		633	119	890				757
PM47								1150								
PM48								429					2060			
PM49	4239											5296				
PM50																

	Furnace Slag															
SITE	**FS1**	**FS1.1**	**FS1.2**	**FS1.3**	**FS1.4**	**FS1.5**	**FS1.6**	**FS2**	**FS2.1**	**FS3**	**FS4**	**FS5**	**FS5.1**	**FS5.2**	**FS6**	**FSND**
PM51			4650					270				1039				
PM52												4930				
PM53																
PM54	11814	1010						23	1140	760	516			110		
PM55	10550	870	4120		1670				1024			5140	1240		190	
PM56	8750			3650					210							
PM57																
PM58		3130	1670		1350			388	780	1400		6157	3010	1896		
PM59																
PM60			1370						1272			1420				1801
PM61																
PM62																
PM63	10640							890				560			1560	
PM64	5269										40			70		
PM65			4010					100	707							
PM66																
PM67																
PM68																
PM69	3120		2920					234								
PM70																
PM71																
PM72								50								
PM73			4130					901								
PM74		5330	4551					558		2823	1480	4327	6365		335	120
PM75			5550							1446		849				
PM76														545		320
PM77	1130	6330														
PM78																

	Furnace Slag															
SITE	**FS1**	**FS1.1**	**FS1.2**	**FS1.3**	**FS1.4**	**FS1.5**	**FS1.6**	**FS2**	**FS2.1**	**FS3**	**FS4**	**FS5**	**FS5.1**	**FS5.2**	**FS6**	**FSND**
PM79	6140				534					70					430	
PM80	1290										32				990	
PM81																
PM82													229			
PM83	490								527			410				
PM84		810										1663				
PM85		9456						440	260			820				
PM86																
PM87	960									2722						
PM88											500		840		125	
PM89								192		50						
PM90										1486			217			
PM91	730							254	1550	440		607			798	
PM92								300				470				
PM93	2330								1010			520				
PM94									390						249	
PM95	2470											2670				
PM96																
PM97	3590															
PM98																730
PM99								880	2330	870		4640				
PM100			3090		1340				3743	620		903				390
PM101										1270					850	
PM102								430		120					690	380
PM103																310
PM104									2860				1100			
PM105																
PM106								600								

	Furnace Slag															
SITE	**FS1**	**FS1.1**	**FS1.2**	**FS1.3**	**FS1.4**	**FS1.5**	**FS1.6**	**FS2**	**FS2.1**	**FS3**	**FS4**	**FS5**	**FS5.1**	**FS5.2**	**FS6**	**FSND**
PM107																
PM108		740							2630	480		1010	760			
PM109																
PM110		2490												130	81	
PM111		390							240						200	
PM112	13460	480										2120			110	
PM113										340			440		180	
PM114																
PM115													1160			
PM116	760															
PM117										1170						
PM118									1200			7530	430		100	
PM119				3330						190					3260	
PM120								80								
PM121										280						
PM122																
PM123																
PM124													150			
PM125	5250							1230	1310	200						
PM126																
PM127	870								520		414			61		
PM128	10050	110	10050				13590		4150							
PM129			1480						250	1120						
PM130					2310						135	520	410			
PM131		2240						551								
PM132	8670	950							430						660	
PM133																
PM134		1063							65			2150	980		80	

	Furnace Slag															
SITE	**FS1**	**FS1.1**	**FS1.2**	**FS1.3**	**FS1.4**	**FS1.5**	**FS1.6**	**FS2**	**FS2.1**	**FS3**	**FS4**	**FS5**	**FS5.1**	**FS5.2**	**FS6**	**FSND**
PM135																
PM136																
PM137																
PM138																
PM139	6640															
TOTAL	144782	39249	102291	32543	7204	9070	13590	16680	61450	30254	3826	84723	29741	4372	16981	6668
No. of sites	31	16	18	4	5	1	1	28	30	28	10	36	22	8	21	10

Appendix B.3 – Furnace Wall and Tuyere by Site

This appendix presents the quantity in weight (g) of each furnace slag sub-type from each site.

	Furnace Lining/Wall									**Tuyere**								
SITE	**FW1**	**FW2**	**FW3**	**FW4**	**FWND1**	**FWND2**	**FWND3**	**FWND4**	**FWND**	**T1**	**T2**	**T3**	**T4**	**TND 1**	**TND2**	**TND3**	**TND4**	**TND**
PM1																		
PM2																		
PM3			370			2471				2756								
PM4						124												
PM5																		
PM6																		
PM7																		
PM8																		
PM9						220												
PM10					37													
PM11																		
PM12																		
PM13																		
PM14	1290					290	900											
PM15																		
PM16																		
PM17																		
PM18	1230	2542	2370				1760		1480						279			
PM19								50										
PM20								220										
PM21					210						42							
PM22					470						49							

	Furnace Lining/Wall									Tuyere								
SITE	**FW1**	**FW2**	**FW3**	**FW4**	**FWND1**	**FWND2**	**FWND3**	**FWND4**	**FWND**	**T1**	**T2**	**T3**	**T4**	**TND 1**	**TND2**	**TND3**	**TND4**	**TND**
PM23																		
PM24					295		5629				190							
PM26							340											
PM27					210		420											
PM28						700		117		2072								
PM29																		
PM30	510																	
PM25																		
PM31						430				3868								
PM32																		
PM33																		
PM34					106	331	1270	189			125							
PM35	1380															544		
PM36																		
PM37																		
PM38						21												
PM39						562												
PM40						2793					57							
PM41																		
PM42	2260				390	232												
PM43																		
PM44	2231						680				35							
PM45	1853					684					483							
PM46	18480						4250				1414							80
PM47	3880						2160				81							
PM48			2010			340												
PM49	3323		779					552			2930							
PM50																		

	Furnace Lining/Wall									**Tuyere**								
SITE	**FW1**	**FW2**	**FW3**	**FW4**	**FWND1**	**FWND2**	**FWND3**	**FWND4**	**FWND**	**T1**	**T2**	**T3**	**T4**	**TND 1**	**TND2**	**TND3**	**TND4**	**TND**
PM51						430												
PM52	1790		2429								187							
PM53																		
PM54					120		522				197	531						
PM55	4071		2040		3070	350	4430				282	650						40
PM56	1610				2355		963				13990	840						40
PM57	1232	651									1459							
PM58	2220	5776				875	30			2846	4786							
PM59																		
PM60	345					3350	1975			32	102						210	
PM61																		
PM62							240			238								
PM63	2356				534	179				2243	633							
PM64											4989							
PM65					226	566						3521						
PM66																		
PM67																		
PM68																		
PM69	370																	
PM70						60	100											
PM71																		
PM72	380						2760											
PM73	8437										193							
PM74	3355					6096		286			435		689					
PM75						725						1334						
PM76	646						2150				1964							
PM77	340						590		1052		1245							
PM78																		

	Furnace Lining/Wall									Tuyere								
SITE	**FW1**	**FW2**	**FW3**	**FW4**	**FWND1**	**FWND2**	**FWND3**	**FWND4**	**FWND**	**T1**	**T2**	**T3**	**T4**	**TND 1**	**TND2**	**TND3**	**TND4**	**TND**
PM79	844						120				573							
PM80	400					563	760				1141	212						
PM81																		
PM82	3140						750											
PM83	1570				513						745							
PM84	615						1782				660							
PM85	390					120					650							
PM86																		
PM87			3580		90			173										
PM88			480		160	684	1150				801	274						
PM89			73															
PM90			812			158												
PM91	682		438		30	400					50							
PM92	3910					3340					50							
PM93	2960		486								310							
PM94	130					40												
PM95	5893										542							
PM96							80											
PM97					128													
PM98																		
PM99	3490				770	1830	2040				5950							50
PM100	16135				842	1388	8490		1170		2244							40
PM101					142													
PM102					1737							302						
PM103							1580											30
PM104	80					810				362								
PM105																		
PM106					320		534				80						90	

	Furnace Lining/Wall									**Tuyere**								
SITE	**FW1**	**FW2**	**FW3**	**FW4**	**FWND1**	**FWND2**	**FWND3**	**FWND4**	**FWND**	**T1**	**T2**	**T3**	**T4**	**TND 1**	**TND2**	**TND3**	**TND4**	**TND**
PM107																		
PM108						140			240									320
PM109																		
PM110					595													113
PM111						580					280							
PM112	798	1758				1070	530				680			605				350
PM113	3480			4010			730		1400		881							
PM114						670												
PM115						13	940											
PM116	1150		1250				1030				166							
PM117					660	440												
PM118	550		415			1647	840				1314	149						
PM119		1502	2390		330			68	498		410			1480				
PM120	150					90	2546				495							110
PM121					70													
PM122																		
PM123					94													
PM124	760						100				65							
PM125	390				180	130	480				264				30			
PM126																		
PM127	1300				1580	670					1625							
PM128	1750					520					2874			834				
PM129	650					340	120											60
PM130	388					538					20				25			
PM131	350					2920	260											
PM132	3246		1220			881					1410							
PM133					50					230								
PM134	3402				800	650					2104							

	Furnace Lining/Wall									Tuyere								
SITE	**FW1**	**FW2**	**FW3**	**FW4**	**FWND1**	**FWND2**	**FWND3**	**FWND4**	**FWND**	**T1**	**T2**	**T3**	**T4**	**TND 1**	**TND2**	**TND3**	**TND4**	**TND**
PM135																		
PM136																		
PM137																		
PM138																		
PM139						440												
TOTAL	122192	12229	21142	4010	17114	42901	56031	1655	5840	14647	62252	7813	689	2919	334	544	300	1233
No. of sites	51	5	16	1	31	49	39	8	6	9	50	9	1	3	3	1	2	11

Appendix B.4 – Crucible, Glassy Slag, Iron, Ore and Geological by Site

This appendix presents the quantity in weight (g) of each crucible, glassy slag, iron, ore and geological sub-type from each site.

	Crucible				Glassy Slag		Iron				Ore		Geological					
Site	**C1**	**C2**	**C3**	**CND**	**GS1**	**GS2**	**I1**	**I2**	**I3**	**I4**	**O1**	**O2**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
PM1																		
PM2																		
PM3								50										
PM4																		
PM5											1273							
PM6											2866							
PM7																		
PM8											1							
PM9				448							290							
PM10														28				
PM11														910				
PM12												1336						
PM13											479							
PM14											1980							
PM15																		
PM16																		
PM17											7921							
PM18		2270		60	5													10370
PM19		546																
PM20											310							
PM21																		
PM22																		

	Crucible				**Glassy Slag**		**Iron**				**Ore**		**Geological**					
Site	**C1**	**C2**	**C3**	**CND**	**GS1**	**GS2**	**I1**	**I2**	**I3**	**I4**	**O1**	**O2**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
PM23																		
PM24											1359		6540					
PM26													6390					
PM27											580							
PM28											220							
PM29											648							
PM30								50										
PM25																		
PM31											474							
PM32																		
PM33																		
PM34											702	1630	7380					
PM35											442		460					
PM36																		
PM37																		
PM38								11			470							
PM39							466											
PM40																		
PM41																		
PM42																		
PM43																		
PM44																		
PM45								57										
PM46																		
PM47														19				
PM48																		
PM49									392									
PM50																		

	Crucible				Glassy Slag		Iron				Ore		Geological					
Site	**C1**	**C2**	**C3**	**CND**	**GS1**	**GS2**	**I1**	**I2**	**I3**	**I4**	**O1**	**O2**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
PM51																		
PM52																		
PM53																		
PM54		550			37							920						
PM55					1350													
PM56																		
PM57											64							
PM58		2132			856						179						2300	
PM59										13		1630						
PM60	15923				557													
PM61																		
PM62	3914					54												
PM63									61									
PM64																		
PM65	5354				1611	151												
PM66	29				23													
PM67	2743				285													
PM68																		
PM69																		
PM70																		
PM71																		
PM72																		
PM73											113							
PM74			952					489	765	6		1107						
PM75			4757												1400			
PM76																		
PM77																		
PM78																		

	Crucible				Glassy Slag		Iron				Ore		Geological					
Site	**C1**	**C2**	**C3**	**CND**	**GS1**	**GS2**	**I1**	**I2**	**I3**	**I4**	**O1**	**O2**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
PM79								91										
PM80							82											
PM81																		
PM82							194											
PM83										29								
PM84				158							83		949					
PM85																176		
PM86																		
PM87				156														
PM88		2713			167									249				
PM89				10														
PM90														165		250		
PM91				210														
PM92																		
PM93																		
PM94											920							
PM95																		
PM96																		
PM97														103				
PM98											410							
PM99																		
PM100											629							
PM101			146															
PM102			3110	180	250			13							975			
PM103			2220												865			
PM104																		
PM105																		
PM106	7789				955													

	Crucible				Glassy Slag		Iron				Ore		Geological					
Site	**C1**	**C2**	**C3**	**CND**	**GS1**	**GS2**	**I1**	**I2**	**I3**	**I4**	**O1**	**O2**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
PM107																		
PM108											330							
PM109																		
PM110											57	160						
PM111																		
PM112							52				246							
PM113																		
PM114												661						
PM115									62		190							
PM116								82	506									
PM117																		
PM118									41	112								
PM119		497			251			49	39	13								
PM120									71									
PM121																		
PM122											222							
PM123																		
PM124																		
PM125								184										
PM126																		
PM127																		
PM128		1545			2221			86			930							
PM129																		
PM130								106										
PM131								13			330							
PM132								49										
PM133		80						31									735	
PM134								137			243							

	Crucible				Glassy Slag		Iron				Ore		Geological					
Site	**C1**	**C2**	**C3**	**CND**	**GS1**	**GS2**	**I1**	**I2**	**I3**	**I4**	**O1**	**O2**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
PM135																		
PM136											1910							
PM137																		
PM138																		
PM139																		
TOTAL	35752	10333	11185	1222	8568	205	794	1498	1937	173	26871	7444	21719	1474	3240	426	3035	10370
No. of sites	6	8	5	7	13	2	4	16	8	5	32	7	5	6	3	2	2	1

Appendix C – Assemblage Typology

Appendix C.1 – Tap Slag

Tap slag fragments were one of the most abundant material types recovered during the 2010 Pioneering Metallurgy Project. Most of the slag recovered is fragmentary with few surviving whole. However, the majority have well preserved top and bottom surfaces which have enabled the identification of several sub-types of tap slag. This section will deal with their descriptions. Table 1 below shows the weight in grams and general dimensions of the different types of tap slag found in each location. Photographs relate to the text directly preceding them.

Table 1: Weights in grams and size range of all tap slag fragments by type in each location.

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
25/01/10 (3)	1	460	1	Dark greyish blue – orangey dark red patches	111	78	37	SP	S	<11	?
25/01/10 (6)	3	3030	1	Dark greyish blue	243	139	78	S-SP	S G	<10	none
	1	4116	21	Dark greyish blue – dark orangey brown patches	16-87	16-57	14-42	SP	S G E	<13 <75	10-33
	1	590	1	Dark greyish blue – dom dark brown – shiny crystallisation	134	52	54	S	S G E few	<11 <41	flat
26/01/10 (7)	1	7569	16	Dark greyish blue – dark brownish red patches	30-176	27-105	20-58	S-SP	S E	<23 <63	20-70
	3	1380	1	Dark grey – dark purplish patches	201	82	62	S-SP	S	<8	none
26/01/10 (8)	1	4418	20	Dark grey – brown patches	35-140	30-103	29-61	S-SP	S G E	<23 <36	13-40
28/01/10 (1)	1	4208	27	Dark greyish blue (some shiny) – dark purplish patches – some pale green	38-139	25-107	26-53	S-SP	S G E N	<12 <115	13-34
	2	240	2	Dark greyish blue – brown patches	67 79	44 66	25 18	S-SP	S G	<12 M<4	9-16
28/01/10 (2)	1	2850	19	Dark greyish blue – dark pale green	29-93	28-77	18-59	S-SP	S G E N	<15 <80	12-33
28/01/10 (5)	1 large	5520	8	Dark greyish blue – dark red patches	40-180	26-127	20-75	S	S G E	<20 <56	17-83
	1.2	1340	2	Dark greyish blue – dark red + brown patches –	97 116	69 95	44 50	S-SP	S G E	<14 <85	crimpled

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
				shiny crystallisation							
	1.1	700	2	Dark greyish blue – dark re patches – shiny crystallisation	79 105	38 80	38 38	S- SP	S G	<10	?
29/01/10 (1)	2	6180	17	Dark greyish blue – pale green – dark red patches	38- 203	27- 168	11- 85	S- SP	S G E few	<15 <45	5-25
	1.1	1610	3	Dark greyish blue – dark red patches – shiny crystallisation	118- 103	66- 78	38- 70	S	S G E	<24 <43	23-51
29/01/10 (3)	2	1150	4	Dark greyish blue – dark pale green	65- 110	53- 80	28- 50	S- SP	S G E few	<13 <23	6-20
	1.1	3420	9	Dark grey – shiny crystallisation	35- 113	27- 97	32- 49	S	S G E	<15 <66	?
29/01/10 (4)	1	2388	12	Dark greyish blue – dark red patches - shiny crystallisation	28- 162	23- 82	12- 43	S- SP	S G E	<15 <56	14- 69
	1.1	3190	7	Dark grey – dark pale green – shiny crystallisation	80- 134	38- 65	41- 85	S- SP	S G E	<14 <58	?
29/01/10 (5)	1.1	960	10	Dark grey – dark reddish orangey patches	31- 75			S	S G	<8	?
30/01/10 (1)	1	601	5	Dark greyish blue – dark red + orange patches – pale green base	53- 115	39- 74	21- 35	S- SP	S G	<8	10-54
30/01/10 (2)	1.1	1320	1	Dark greyish blue – shiny crystallisation	147	101	59	S- SP	S G E few	<13 <60	?
	1 thin	1207	22	Dark greyish blue – brownish orange patches	33- 86	21- 61	13- 33	S- L	S G	<13	12-25
01/02/10 (1)	2	5251	11	Dark greyish blue – dark brownish red patches	20- 205	18- 161	6- 80	SP	S G E	<17 <30	6-24 – 1 lg start of flow
	1.1	2010	17	Dark grey – purple patches – shiny crystallisation	41- 130	27- 98	36- 47	SP- P	S G E	<20 <36	?
01/02/10 (2)	1	137	3	Dark greyish blue – top dom dark brownish purple red	25 51	20 48	38 38	S- P	S G E	<6	none
01/02/10 (3)	1	530	2	Dark grey blue/purple	54 101	38 98	34 42	P	S	M <10	15-35
01/02/10 (4)	1	600	2	Dark greyish blue/purple	85 95	55 63	60 44	S- SP	S G	M <11 Up to 20	14-42
	3/1 st of flow	780	1	Dark greyish blue – dark red patches	120	98	86	S- SP	S G E few	<8 <40	17-47
01/02/10 (5)	2 drip	4310	1	Dark greyish blue – dark red	244	173	105	S	S G	<10	4-20
	1/2	570	6	Dark greyish blue	45- 58	28- 56	25- 26	S	S G	<6	12-25
	3	230	1	Dark greyish blue	63	62	33	S- SP	S G	<5	?
01/02/10 (7)	1.2	890	4	Dark greyish blue – dark red patches	46- 99	38- 81	23- 38	SP	S G	<9	23-33

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
	1.1	850	2	Dark greyish blue – brown + orangey patches	65 83	53 74	53 49	S	S E	<8 <40	?
01/02/10 (8)	1	2330	14	Dark greyish blue dark purplish red patches	36-100	32-77	29-59	S	S G	M <11	16-47
	1.1	1450	2	Dark greyish blue – mid brown patches	67 133	54 104	35 69	S	S E	M <6 < 53	?
	3/1.2	1010	4	Dark greyish blue	65 - 125	38 - 87	22-48	SP	S G	<13	?
02/02/10 (1)	1.2?	2440	2	Dark greyish blue – mid brown patches	78 222	74 146	55 73	P	S G	M <11	?
02/02/10 (4)	1	2049	19	Dark greyish blue – dark red patches	25-97	22-73	22-40	S-SP	S G E	M <7 <61	8-52
02/02/10 (5)	1	1050	4	Dark greyish blue – some dark red/ purple patches	71-87	45-80	37-47	SP	S G E	M <8 <59	13-63
02/02/10 (6)	2	1208	4	Dark greyish blue – some purple patches	30-121	24-103	12-61	SP	S G E	<6 <47	8-26
	1	1357	24	Dark greyish blue – dark red/ purple – dark pale green	30-92	18-55	19-92	SP	S G	<8	8-34
	1.1	800	8	Dark grey – shiny crystallisation	39-85	29-57	22-34	S-SP	S G E few	<8 <39	?
02/02/10 (7)	1	60	1	Dark greyish blue	53	43	20	SP	S G	<7	?
	1.1 or PCB	290	1	Dark greyish blue	73	50	48	SP	SG N E	<5 <30	?
02/02/10 (8)	1	912	16	Dark greyish blue – dark brownish red + orange patches	<61		<28	S-SP	S G	<8	12-37
	3	213	1	Dark greyish blue – dark brownish red + orange patches	102	49	51	S-L	S G	<8	shaped
03/02/10 (1)	1	816	9	Dark greyish blue – dark purplish patches	39-77	30-54	24-35	S	S	<6	12-58
	1.1	1710	9	Dark greyish blue – shiny metallic – dark red patches	45-95	41-56	27-40	S	S E	<12 <53	?
03/02/10 (3)	1.1	1420	2	Dark greyish blue – dark red patches	108 127	67 93	43 43	S	S E	<6 <30	?
	2	565	7	Dark greyish blue – dark red patches	26-70	21-46	21-39	SP	S G	<6	10-22
	1.2	4580	2	Dark grey – dark red and mid grey patches	141-185	121-177	69-83	S-SP	S G E	<19 <50	?
03/02/10 (4)	1.1	1390	3	Dark greyish blue – shiny crystallisation	62-111	50-75	45-62	S	S E	<6 <62	?
	1.2	1010	1	Dark greyish blue – dark red patches	168	109	63	S SP	S G E	<8 <40	?
	2	400	4	Dark greyish blue – dark red patches – some pale green	60-81	25-75	12-48	SP	S G	<9	8-25

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
03/02/10 (6)	1	1463	2	Dark greyish blue – dark red + orange patches	126 119	86 107	43 63	SP	S G E	<6 <35	14-34
	1.1	680	3	Dark greyish blue – dark red patches – shiny crystallisation	59-57	48-61	51-60	S-SP	S G E	<8 <30	?
03/02.10 (9)	1	1326	11	Dark greyish blue – dark red patches	24-97	22-93	22-35	S-SP	S G E few	<8 <31	20-38
	1.1	1060	1	Dark greyish blue – dark brownish red orange patches	139	63	70	S-L	S G	<13	
	1.2	1390	1	Dark greyish blue – dark red patches	165	120	58	S P	S G E	<12 <47	?
03/02/10 (10)	1.1 v large	3330	2	Dark greyish blue - small orange patches – shiny crystallisation	84 207	48 108	42 112	S-SP	S G E	<12 <100	?
	1.2	695	1	Dark greyish blue – yellowy brown patches – shiny crystallisation	142	88	49	S- L	S G	<7	crimpled
03/02/10 (11)	1.1	2100	6	Dark greyish blue – dark brownish red patches. shiny crystallisation	53-123	27-123	33-41	S	S G E few	<6 <65	?
	1 v large	3420	2	Dark greyish blue – dark brownish red patches. shiny crystallisation	110 173	85 144	75 83	S-SP	S G E	<11 <70	?
03/02/10 (12)	1.1	590	2	Dark greyish blue – shiny crystallisation	77 84	39 70	43 33	S	S G	<10	?
	1	283	3	Dark greyish blue – dark brownish red patches - some pale green	36-71	25-47	22-35	L-SP	S G	<5	15-22
03/02/10 (13)	1.1 v large	7930	3	Dark greyish blue – dark red patches – shiny crystallisation	88-301	60-198	82-72	S-SP	S G E	<11 <70	?
	1	80	2	Dark greyish blue	39 50	35 35	27 23	SP	SG	<3	15-17
03/02/10 (14)	1	3360	9	Dark greyish blue – dark red patches – shiny crystallisation	58-143	32-58	27-48	S-SP	S G E few	<25 <33	10-44
	1.2 v large	1440	1	Dark greyish blue – dark red patches – shiny crystallisation	126	97	91	S-P	S G E	<7 <50	?
03/02/10 (15)	1.1	1840	4	Dark greyish blue – dark red patches – shiny crystallisation	69-80	45-62	32-43	S-SP	S G Ver E few	<10 <20	?
	1/1.2 v large	8319	4	Dark greyish blue – dark red patches – some crystallisation	41-253	44-220	32-91	S-P - VP	S G E few	<17 <58	40-100
	3	220	1	Dark greyish blue – dark red patches	67	60	33	SP	SG	<4 up to 14	?

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
	1	130	1	Dark grey – purple patches – crystallised	64	55	44	VP	S G	<15	flat
05/02/10 (1)	1 v large	13880	11	Dark greyish blue – dark red patches – shiny crystallisation	42-249	28-152	23-95	S-SP	S G E	<13 <100	15-95
05/02/10 (2)	1/1.1 v large	7807	11	Dark greyish blue – dark red patches – shiny crystallisation	58-177	46-124	35-103	S-P	S G E	<15 <73	?
	1.1 shiny black	1140	1	Dark shiny metallic grey	113	93	60	S	S G	<12	?
05/02/10 (3)	1	2263	6	Dark greyish/ purplish blue – dark red patches – shiny crystallisation	38-169	34-147	18-68	SP-P	S G	<11	10-40
	1.1	640	2	Dark greyish blue – dark red patches – shiny crystallisation	68-	47-	45-	S	S G E	<7 <54	?
05/02/10 (4)	1	551	3	Dark greyish blue – dark red + yellowy orange patches – shiny crystallisation	48-87	37-64	9-35	S-SP	S G	<16	10-30
05/02/10 (5)	1/1.1	1950	4	Dark greyish blue – dark red patches – shiny crystallisation	93-113	95-51	42-95	S-P	S G	<14	?
05/02/10 (6)	1 v large	7921	9	Dark greyish blue – dark red patches – shiny crystallisation	32-167	30-132	28-84	S- L	S G E	<16 <88	16->100
05/02/10 (7)	1	1530	7	Dark greyish blue – dark red patches – shiny crystallisation	62-95	51-49	25-40	S	S G	<10	20-39
	1.1	940	2	Dark greyish blue – dark red patches – shiny crystallisation	54 95	59 78	48 57	S	S G E few	<1 <40	?
06/02/10 (2)	1	210	1	Dark greyish blue – dark red patches	72	54	37	S	S G	<8	8-26
	1.1	1450	2	Dar greyish blue – dark red patches shiny crystallisation	129 113	76 70	41 62	S-SP	S G	<10	?
06/02/10 (3)	1.1	1691	3	Dark grey – shiny crystallisation – dark red patches	80-123	44-84	70-52	S- L	S G	<30	?
08/02/10 (1)	2	576	2	Dark greyish blue – dark yellowy orange + orange patches	118 121	96 93	42 25	SP	S G	<15	5-25
	1/2	300	5	Dark greyish blue – dark red patches	40-63	30-55	21-31	SP	S G	<9	10-30
08/02/10 (2)	1/2	1190	8	Dark greyish blue – dark red patches	49-100	38-80	19-55	SP	S G	<9	10-40
08/02/10 (4)	2	2515	14	Dark greyish blue – dark red +	50-134	28-81	27-49	SP-P	S G	<17	6-21

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
				orange patches – pale green							
08/02/10 (5)	2	1060	5	Dark greyish blue – dark red patches	49-102	24-98	27-47	SP	S G	<9	6-21
08/02/10 (9)	2	2750	8	Dark greyish blue – dark red patches	58-149	27-106	22-58	SP	S G	<12	6-40
	2/3 st of flow	2970	1	Dark greyish blue – dark brownish red patches	245	113	70	SP	S G	<12	<25
	3.1	710	2	Dark greyish blue – dark brownish red patches	122 145	28 62	25 54	S-SP	S G	<8	?
	1.1	791	2	Dark greyish blue – shiny crystallisation	78-?	30	43	S	S G E ver	<5 <20	?
08/02/10 (10)	2	7277	10	Dark greyish blue – dark red patches – pale green base	44-238	24-213	21-93	SP-P	S G	<17	7-31
	1.1	170	1	Dark greyish blue shiny – dark red patches	51	33	43	S	S G	<9	?
	1	840	1	Dark greyish blue shiny – dark red patches	173	80	43	S-SP	S G	M <9	80
08/02/10 (11)	1	1174	2	Dark greyish blue – brown + dark brownish red patches	<150			SP	S G	<32	<43
09/02/10 (1)	2	368	6	Dark grey to shiny black – light grey + dark orangey brown patches	45-102	25-81	29-44	S- L	S G	<17 m<5	5-15
09/02/10 (2)	2	1565	5	Dark greyish blue – mid grey + dark orangey brown patches				S- L	S G	<17 m<5	5-31
09/02/10 (4)	1?	101	1	Dark greyish blue – mid grey + dark orangey brown patches	<75			SP	S G	<4	?
09/02/10 (5)	2	3730	6	Dark greyish blue – mid grey + dark orangey brown patches	84-186	37-158	38-63	L- SP	S G E	<14 <30	5-17
09/02/10 (6)	3	1140	1	Dark greyish blue – dark red + orange patches	145	86	63	S-SP	S G	<9	17-37
09/02/10 (7)	1	2024	15	Dark greyish blue – dark red patches – pale green base	38-115	18-107	13-56	S-SP	S G E few	<16 <43	12- 43
	1.1	610	2	Dark greyish blue – shiny crystallisation	47-98	38-79	48-30	S	S G	<8	?
10/02/10 (1)	2	490	2	Dark greyish blue – dark red patches	47-117	34-51	23-51	S	S G	<6	10-20
10/02/10 (2)	1	40	1	Dark greyish blue	36	27	24	S	S G	<10	12- 19
10/02/10 (4)	1	142	3	Dark greyish blue	<65			S- L	S G	<10	<26
11/02/10 (1)	1	350	2	Dark greyish blue – dark red patches	58-89	48-72	40-27	SP	S G	<15	10-27

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
11/02/10 (2)	1	790	6	Dark greyish blue – dark red patches – pale green base	47- 102	34- 106	19- 54	S - SP	S G	<13	7-48
	1.1	850	4	Dark greyish blue – shiny crystallisation	42- 94	29- 52	43- 36	S	S G E few	<7 <61	?
11/02/10 (5)	1 some large	2797	7	Dark greyish blue – dark red patches	25- 113	17- 80	18- 81	S- SP	S G E	<16 <54	13-40
	1.2	1339	2	Dark greyish blue shiny	104 117	73 112	49 54	S- L	S G E few	<9 <40	crimpled
11/02/10 (6)	1	2190	2	Dark greyish blue – shiny crystallisation – dark red patches	84 145	69 147	30 89	S- SP	S G E	<20 <76	15-70
12/02/10 (1)	1	270	5	Dark greyish blue – dark red + brown patches	38- 58	24- 64	25- 30	SP	S G E	<8 <30	?
A3	3	2245	lot	Dark greyish blue – dark orangey brown + brown + whitish grey patches	29- 164	28- 82	24- 59	SP	S G E	<25	Mostly none <80
C19	1/3	1829	lot								
A8	2? agita ted	2477	lot	Dark greyish blue – whitish grey + brown orange + red patches	<20 0			SP- P	S G E	<5 <23	15-25 mainly trickles
12/02/10 (6)	1	790	2	Dark greyish blue – shiny crystallisation	84 115	62 65	38 59	S	S G	<19	?
12/02/10 (7)	1?	270	1	Dark greyish blue – dom mid brown	70	72	42	S	S G	<3	?
12/02/10 (8)	1.2	1070	3	Dark greyish blue – dark red + mid grey patches	88- 131	35- 83	34- 45	SP- P	S G	<12	?
12/02/10 (10)	1	220	3	Dark greyish blue – dark brown + red patches	47- 60	46- 43	24- 30	S- SP	S G	<6	15-28
13/02/10 (1)	1/1.1 very large	12086	6	Dark greyish blue – dark red/purple + brown patches – shiny crystallisation	74- 299	58- 173	31- 104	S	S G E	<18 <170	20-155
	1	1820	1	Dark greyish blue – dark brown patches – shiny crystallisation	159	123	62	S	S G	<6	none
	3	510	1	Dark greyish blue – mid brown + orange patches	108	77	60	S- P	S G I	<19	?
13/02/10 (2)	1/1.1	800	3	Dark greyish blue – shiny crystallisation – dark red patches	60 104	48 88	22 41	S	S G	<10	?
13/02/10 (3)	1	570	2	Dark greyish blue – dark red patches – pale green base	96 96	59 70	35 34	S P	S G	<13	11-26
13/02/10 (6)	1/1.1	490	2	Dark greyish blue – dark red patches – shiny crystallisation	76 83	56 70	43 35	S- SP	S G E	<11 <45	16-25
13/02/10 (7)	2	290	1	Dark greyish blue - pale green	95	76	32	S	S G	<5	6-16

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
	1.1	420	1	Dark greyish blue shiny – dark red patches	113	58	41	S	S G	<6	?
13/02/10 (8)	1.1	450	2	Dark greyish blue – dark red patches	54 83	45 54	17 50	S	S G	<8	?
13/02/10 (9)	1.1	480	1	Dark greyish blue – dark red patches – shiny crystallisation	88	61	48	S	S G	<4	?
	1	300	2	Dark greyish blue – dark red patches – shiny crystallisation	39 67	31 62	23 37	S	S G E few	<6 <25	15-44
13/02/10 (10)	1/1.1	3320	10	Dark greyish blue – dark red patches	57- 132	35- 80	36- 67	S- SP	S G E few	<8 <51	22-42
13/02/10 (11)	1.1	980	1	Dark greyish blue – dark red + brown patches	135	97	55	S- SP	S G E	<7 <63	?
13/02/10 (12)	1	490	1	Dark greyish blue – mid brown patches	107	76	55	SP- P	S G E	<12 <28	10-31
13/02/10 (13)	1/1.2	473	2	Dark greyish blue – dark brownish red patches	79 90	61 68	27 45	L- SP	S G E	<5 <40	? <30 – 1 crimpled
13/02/10 (14)	1 large	2990	3	Dark greyish blue	67- 152	38- 115	55- 73	S- SP	S G E	<8 <59	15-85
13/02/10 (15)	1 large	16441	1	Dark greyish blue – dark reddish brown patches	445	264	76	S- SP	S G E	<14 <110	Almost flat
15/02/10 (1)	1 large	3790	1	Dark greyish blue – dark red patches – shiny crystallisation	187	145	86	S	S G	<10	None – large undulation
	1 thin	167	1	Dark greyish blue – dark grey + dark brown tinge	104	46	18	S	S G	<2	1 tendril flow
15/02/10 (2)	1 large	1670	1	Dark greyish blue – dark red patches – shiny crystallisation	180	69	70	S	S G E	<10 <35	None – large undulation
15/02/10 (3)	1 thin	1221	12	Dark greyish blue – dark red patches	28- 95	20- 65	25- 49	S- SP	S G	<14	9-37
15/02/10 (4)	1	210	1	Dark greyish blue – dark red patches	<10 0			L- SP	S G	<18	<30
16/02/10 (1)	2	160	2	Dark greyish blue – dark red patches	56 58	29 52	16 32	SP	S G	<7	5-14
	1 very large	4850	2	Dark greyish blue – dark red and brown patches	123 167	104 146	86 81	S	S G E few	<16 <25	15- none
	1.1 thick	572	1	Dark greyish blue – heavy shiny crystallisation	92	60	54	S	N	<11	?
16/02/10 (2)	2	1084	4	Dark greyish blue – dark red patches	49- 117	22- 115	25- 42	SP	S G	<9	5-29
	1	240	1	Dark greyish blue – dark red patches	64	55	61	SP- P	S G	<8	41
16/02/10 (5)	1.1	1087	3	Dark grey – dark red and brown patches	76 108	69 50	37 83	S- SP	S G E few	<10 <60	?

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
	1	797	2	Dark greyish blue – dark brownish red patches	<90			SP	S G I	<27	6-30
16/02/10 (6)	1/2	1391	4	Dark grey blue – dark red + light grey + dark brown patches	60-133	41-122	58-52	SP – P	S G	<22	8-40
	1.1	390	1	Dark greyish blue – dark red patches	85	68	48	S	S G	<10	?
17/02/10 (1)	1/1.1	580	3	Dark greyish blue – dark brown + orange patches	67-79	50-62	27-56	SP	S G	<7	17-27?
	1.1?	2370	4	Dark greyish blue – dark red + light grey patches – some crystallisation	61-137	36-75	45-92	S-SP	S G I	<11	?
17/02/10 (2)	1/1.1	5006 1 large	9	Dark greyish (purple) blue – dark red patches – some shiny	37-146	30-126	34-72	S – L	S G	<16	?
17/02/10 (3)	1 thin	1805	2	Dark greyish blue – mid grey + dark red patches	88 200	79 149	36 47	S	S G E few	<10 <40	12-45
	1.2	960	1	Dark greyish blue – dark red patches – shiny crystallisation	153	103	45	S- L	S G E few	<6 <40	crimpled
17/02/10 (4)	1.1	338	1	Dark greyish blue – dark purple patches	102	53	42	S- L	S G E ver	<20 <11	?
18/02/10 (1)	1/1.1	2700	7	Dark greyish blue – dark red + some orange patches	64-98	50-87	20-66	S-SP	S G E few	<12 <32	?
	1.2 v large	2480	1	Dark greyish blue – dark red + brown patches – shiny crystallisation	154	129	86	S-SP	S G	<5	crimpled
18/02/10 (2)	1/1.1	1960	5	Dark greyish blue – dark orange + red patches – some shiny	43-95	38-90	26-50	S-SP	S G E few	M <11 <63	12-20
	1.2	259	1	Dark greyish blue – dark brown patches	69	76	37	L-SP	S G	<5	crimpled
18/02/10 (3)	2	2640	7	Dark greyish blue – dark brown + red patches	28-173	27-173	16-65	S-SP	S G	<7	4-25
18/02/10 (4)	1 thin	930	3	Dark greyish blue – dark red + orange patches	55-136	43-100	30-34	S-SP	S G	<13	12-80
18/02/10 (5)	1/2 thin	1260	6	Dark greyish blue – dark brown patches	65-110	62-88	33-39	S-SP	S G	<19	6-64
18/02/10 (6)	2	1401	10	Dark greyish blue – some dark red patches	55-128	20-115	11-67	L-P	S G	<12	5-16 – 1 tendril
18/02/10 (7)	1	860	5	Dark greyish blue – dark purple patches	49-104	28-70	17-57	S	S G E few	<5 <45	5- 43
19/02/10 (1)	2 large	6709	7	Dark greyish blue/ purple – dom yellowy brown + dark red	57-175	50-163	25-105	SP	S G	<19	5-25

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
	1/1.1	1270	5	Dark greyish blue – dark red + yellowy brown patches	43-106	28-72	19-42	S-SP	S G E	<8 <103	?
	3	704	1	Dark greyish blue – dom dark reddish brown	124	93	63	SP	S G	<32	Start of flow
19/02/10 (2)	2	4080	6	Dark greyish blue – dark red + yellowy brown patches	52-193	15-175	9-58	S	S G	<12	7-38
19/02/10 (3)	2	2340	7	Dark greyish blue – dark red patches	73-129	44-84	22-45	SP	S G	<8	5-37
	1/1.1	1320	3	Dark greyish blue – dark brownish red patches	46-190	43-70	42-54	S-SP	S G	<14	?
	1	750	2	Dark greyish blue – dark red patches + dark brown	105 138	59 77	31 50	S-SP	S G	<15	22-62
	1.1	390	1	Dark greyish blue – dark red patches + dark brown	93	70	42	S-SP	S G E ver	<7 <17	?
19/02/10 (4)	1/1.1 large	7040	3	Dark greyish blue – dark red + brown patches	108-283	96-196	48-64	S	S G E	<13 <76	?
	2	750	lot	Dark greyish blue – dark red + brown patches – some pale green	27-69	20-56	11-33	S-SP	S G	<11	7-33 trickles
19/02/10 (5)	1	2947	14	Dark greyish blue – purple + dark red patches – some pale green	30-128	23-118	12-51	S-SP	S G E few	<12 <53	6-111
19/02/10 (6)	1	1200	7	Dark greyish blue – dark red patches	53-89	36-72	17-47	S-SP	S G	<8	10-36
	1? Large	1280	1	Dark greyish blue – dark red patches	125	108	90	P	S G I	<8	? none
	1.1 large	2580	1	Dark greyish blue – dark red patches	186	167	73	SP	S G I	<18	?
	1/2 start flow?	1600	1	Dark greyish blue – dark red patches	174	132	84	S-SP	S G	<8	6-25
21/02/10 (1)	1.1	1040	10	Dark greyish blue – dark brown + red patches – shiny crystallisation	30-79	29-56	24-39	S-SP	S G	<6	?
	1	70	1	Dark greyish blue – mid grey patches	42	48	24	S	S G	<2	? smooth
21/02/10 (3)	1/1.1	1300	8	Dark greyish blue – dark red + brown patches	42-75	34-70	12-49	S-SP	S G	M<10	?
21/02/10 (4)	1.1	210	3	Dark greyish blue – dark red + brown patches	32-49	18-40	27-45	S-SP	S G	<14	?
21/02/10 (5)	1	130	2	Dark greyish blue – dark red + brown patches	36 60	30 60	24 33	S-P	S G	<7	?

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
21/02/10 (6)	1	850	1	Dark greyish blue – dark red patches	115	98	54	S	S G	<9	? none
21/02/10 (7)	1.1	1030	3	Dark greyish blue – dark brown + red patches	78 95	59 75	36 62	S-SP	S G	<12	? v abraded
22/02/10 (1)	1 large	3320	2	Dark greyish blue – dark red patches	124 148	85 127	72 87	S	S G	M <11	11-63
	1.1	460	1	Mid grey – crystallised – dark brown patches	84	60	38	S	S G	<6	?
	2	2318	12	Dark greyish blue – white and dark brown patches	37-94	25-59	23-54	S- L	S G	<9	4-20
22/02/10 (3)	2	1470	6	Dark greyish blue – dark red/purple patches	23-169	20-104	17-55	SP	S G	<9	6-24
	1.2	1280	1	Dark grey – dom mid grey + brown	155	89	52	S- L	S G	<20	crimpled
22/02/10 (4)	1/1.1	3430	12	Dark greyish blue – dark brown + red patches – some shiny	37-129	32-86	20-37 up to 60	S-SP	S G	<12	? 9-43
	1.2	630	1	Dark greyish blue – crystallised – mid grey patches	132	76	40	SP	S G E few	<12 <28	crimpled
23/02/10 (1)	1	1213	9	Dark greyish blue – dark brown + red patches – some pale green shiny crystallisation	37-92	23-68	22-58	S	S G E few	<12 <63	7-34
23/02/10 (2)	2	2802	8	Dark greyish blue – dark brown + red patches	53-127	52-98	23-52	SP	S G	<12	6-23
	1.1	650	1	Dark greyish blue – mid brown orange + dark red patches	117	63	62	SP	S G E ver	<8 <33	?
23/02/10 (3)	2	1550	5	Dark greyish blue – dark brown + red patches	71 175	56 143	23 78	SP	S G	<10	5-23
	1.1	990	4	Dark greyish blue – some shiny	38-98	40-72	33-46	S	S G	<10	?
	1	160		Dark greyish blue – dark red + orangey brown patches	84	56	41	P	S G I	<5	10-30
23/02/10 (4)	1/2	2480	8	Dark greyish blue – dark brown +red patches	77-138	62-90	32-37	SP	S G	<8	6-30
23/02/10 (5)	2	1150	4	Dark greyish blue – dark red patches	41-144	27-125	15-42	SP	S G	<8	6-25
	3.1	120	2	Dark greyish blue – dark brown + red patches	67 67	29 37	18 20	SP	S G	<6	10-28
23/02/10 (6)	1/1.1 v large	3440	5	Dark greyish blue – dark brown + red patches – shiny crystallisation	52-114	40-78	53-79	S	S G E	<18 <84	?
23/02/10 (7)	1/2	420	4	Dark greyish blue – dark red patches	41-73	41-54	35-37	SP	S G	<10	10-23 1 runnel

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
23/02/10 (8)	1 v large	8440	4	Dark greyish blue – dark red patches – shiny crystallisation	100- 204	83- 126	47- 90	S- SP	S G E few	<14 <130	? some none
	1/2	70	1	Dark greyish blue – dark red patches	55	40	17	S	S G	<4	16-23
23/02/10 (9)	1 v large	5430	2	Dark greyish blue – dark red patches	200 200	140 118	89 72	S- SP	S G E few	<20 <115	21-87
	2	490	1	Dark greyish blue – dark red patches	<11 0			S P	S G E	<7 <13	<15
23/02/10 (10)	1 v large	4240	3	Dark greyish blue – dark red and orange patches	108- 148	76- 120	83- 78	S- SP	S G	<18	10-68
	1 thin	246	6	Dark greyish blue – dark red and orange patches	31- 66	21- 33	25- 27	L- SP	S G	<8	8-28
23/02/10 (11)	1 v large	6400	4	Dark greyish blue – dark red + orangey brown patches – shiny crystallisation	108 196	59 142	50 80	S- SP	S G E few	<14 <135	Upto 63
23/02/10 (12)	1 v large	2638	6	Dark greyish blue – dark red + orangey brown patches – shiny crystallisation	60- 200	38- 96	26- 81	SP	S G	<16	11-58
24/02/10 (1)	1 v large	4590	1	Dark greyish blue – dark red + orangey brown patches – shiny crystallisation	208	137	90	S	S G E	<15 <103	13-48
	1	208	6	Dark greyish blue – dark brown patches	34- 55	28- 54	26- 23	S- SP	S G	<5	13-54
	1.2	1430	1	Dark greyish blue – dark grey/ brown + brownish orange patches	167	104	78	S- SP	S G	<16	crimpled
	2	1040	1	Dark greyish blue – dark red + brownish orange patches	126	105	67	SP	S G	<9	5-16
24/02/10 (2)	1/1.1	2613	18	Dark greyish blue – dark red + orangey brown patches	22- 97	18- 58	8- 49	S- SP	S G	<14	11-41
24/02/10 (3)	1/2	750	6	Dark greyish blue – dark red patches	36- 124	15- 103	10- 36	SP	S G	<13	7-40
	1.1	470	2	Dark greyish blue	82 91	42 49	44 44	S	S G	<7	?
24/02/10 (4)	2	863	8	Dark greyish blue – dark red patches	40- 88	27- 65	24- 45	S- SP	S G	<10	6-24
	1.1	940	1	Dark greyish blue – shiny crystallisation	123	116	53	S	S G few N	<3 <50	?
25/02/10 (1)	1	1450	7	Dark greyish blue – dark red + some orange patches	26- 98	24- 75	10- 59	S	S G	<10	12-47
25/02/10 (2)	1	395	3	Dark greyish blue shiny – dark red patches	48- 60	43- 45	57- 26	S- SP	S G	<6	3-15

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
25/02/10 (3)	1	100	2	Dark greyish blue	33 47	30 30	16 29	S-SP	S G	<6	10-26
25/02/10 (4)	1	360	4	Dark greyish blue – dark red patches – some pale green	42-65	29-45	28-36	S-SP	S G	M<7	12-25
25/02/10 (5)	1/1.1	1270	8	Dark greyish blue – dark red patches	40-63	25-55	30-66	S	S G	<16	?
25/02/10 (7)	1	2328	6	Dark greyish blue – dark red patches	63 120	45 87	53 60	S	S G E	<12 <38	13-28
	1.1	1290	1	Dark greyish blue – shiny crystallisation – dom dark brown	153	91	60	S	S G I	<12	?
25/02/10 (8)	1	290	1	Dark greyish blue – dark red patches – shiny crystallisation	61	52	45	S-SP	S G E few	<8 <36	16-27
	2	170	1	Dark greyish blue – dark orangey brown patches	98	43	23	S	S G	<13	13-22
26/02/10 (1)	1/1.1	6170	14	Dark greyish blue – dark brown + brownish red patches	50-176	32-174	34-80	S	S G E	<10 <53	11-69
26/02/10 (3)	1.1	2860	3	Dark greyish blue – dark red patches	75-173	34-88	53-52	S	S G	<12	?
	1/2	971	5	Dark greyish blue – dark red + brownish orange patches	31-108	30-71	14-42	SP-P	S G	<12	8-33
26/02/10 (4)	1.1	300	1	Dark greyish blue – dark red+ purple patches	64	55	37	S	SG	<11	?
26/02/10 (5)	1/2	1562	5	Dark greyish blue - dark brown + red patches	35-131	23-48	20-22	S-SP	S G	<14	9-38 1 tendril
	1.1	1630	1	Dark greyish blue – shiny crystallisation	137	111	65	S	S G	<4	?
26/02/10 (7)	1/2	1370	4	Dark greyish blue – dark red patches	78-116	64-87	44-45	SP	S G	<14	5-42
	3	1740	3	Dark greyish blue – dark brown + red patches	84-139	40-97	33-70	S-SP	S G	<15	?
26/02/10 (8)	1 sm flows	1454	9	Dark greyish blue – dark red patches	38-93	22-74	18-39	S-SP	S G	<13	23-51
27/02/10 (1)	1	300	13	Dark greyish blue – dark red + purple patches	20-68	18-40	9-31	SP	S G	<12	8-31
27/02/10 (3)	1	710	2	Dark greyish blue – dark red + purple patches	60 88	44 81	35 53	S-SP	S G E few	<12 <54	24-39
27/02/10 (4)	1 v large	1930	3	Dark greyish blue – dark red patches – some orangey brown	54-161	27-95	20-95	S	S G E few	<13 <62	15-41
	1.2 large	1350	1	Dark greyish blue – dark red + brown patches – pale green base	164	96	95	SP-VP	S G	<10	crimpled

Location	Type (TS)	Weight	No	Colour	L	W	T	Porosity			Ripple size
								Deg.	Shape	Size	
	3 lg tdrl	848	3	Dark greyish blue – dark red + brown patches	40-123	35-59	28-48	SP	S G	<12	Crimpled up to 55
27/02/10 (6)	2	2760lg 3399	10	Dark greyish blue – dark brown + red patches – pale green base	57-203	50-144	14-113	L-SP	S G	<15	13-38
	1/1.1	1400	2	Dark greyish blue – dark brown + red patches – some crystallisation	56 95	49 82	44 72	S	S G E few	<11 <57	?
27/02/10 (7)	2	410	1	Dark greyish blue – dark red patches	94	100	30	S-SP	S G	<9	7-30
	1.1	1189	2	Dark greyish blue – dom mid grey + dark reddish brown patches	76 118	50 95	48 55	S	S G few E few	<5 <70	?
	1.2	817	2	Dark grey – dom dark reddish brown patches	63-167	36-120	25-43	SP – P	S G E	<8 <30	crimpled
19/09/09 (6)	1	2060	2	Dark greyish blue – dark red/purple patches – shiny crystallisation	158 145	64 74	59 60	S	S G	<13	19-62
19/09/09 (9)	1	490	1	Dark greyish blue – dark red patches	106	72	54	SP	S G E	<8 <46	23-49
	1.2	530	1	Dark greyish blue – dark red + light grey patches	103	80	49	S-SP	S G	<25	crimpled
20/09/09 (3)	1	600	7	Dark greyish blue – dark red patches	35-78	29-55	35-33	S-SP	S G	<10	8-23

Key:
Colour
Dom – dominated

Porosity
S – solid SP – semi porous P – porous VP – very porous

Porosity shape
S – spherical G – globular E – elongated N – networked I – irregular

Appendix C.1.1 – TS1

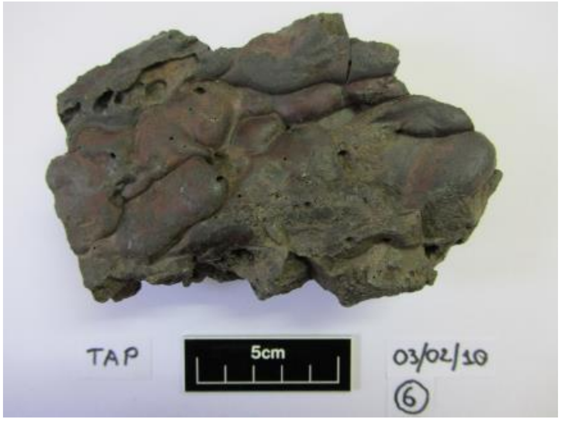
Characteristic features	Rippled smooth top surface; undulated bottom surface; dark greyish blue in colour often with varying shades of dark red/purple and brown patches; mostly solid to semi porous
Size range	Wide range of sizes from the smallest fragment 16mm in length, 16mm in width and 14mm in thickness to the largest fragment 445mm in length, 264mm in width and 76mm in thickness. The thickness of some of the larger fragments can be up to 104mm.
Locations in which found	25/01/10 (3) (6), 26/01/10 (7) (8), 28/01/10 (1) (2) (5), 29/01/10 (4), 30/01/10 (1) (2), 01/02/10 (2) (3) (4) (5) (8), 02/02/10 (4) (5) (6) (7) (8), 03/02/10 (1) (6) (9) (12) (13) (14) (15), 05/02/10 (1) (2) (3) (4) (5) (6) (7), 06/02/10 (2), 08/02/10 (1) (2) (10) (11), 09/02/10 (4) (7), 10/02/10 (2) (4), 11/02/10 (1) (2) (5) (6), 12/02/10 (1) A3 C19 (6) (7) (10), 13/02/10 (1) (2) (3) (6) (9) (10) (12) (13) (14) (15), 15/02/10 (1) (2) (3) (4), 16/02/10 (1) (2) (5) (6), 17/02/10 (1) (2) (3), 18/02/10 (1) (2) (4) (5) (7), 19/02/10 (3) (4) (5) (6), 21/02/10 (1) (3) (5) (6), 22/02/10 (1) (4), 23/02/10 (1) (4) (6) (7) (8) (9) (10) (11) (12), 24/02/10 (1) (2) (3), 25/02/10 (1) (2) (3) (4) (5) (7) (8), 26/02/10 (1) (3) (5) (7) (8), 27/02/10 (1) (3) (4) (6), 19/09/09 (6) (9), 20/09/09 (3)

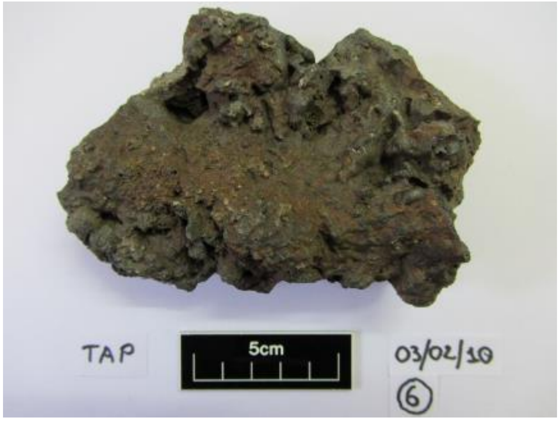
Material fragments of this type comprise the majority of the tap slag recovered. The fragments are all fragmentary with none or very few surviving intact but the majority have surviving top and bottom surfaces. They all vary in shape and size but the major characteristic features which define this tap slag type are their well rippled, mostly smooth top surfaces, undulated bottom surfaces; dark greyish blue colour often with varying shades of dark red/purple and brown patches and the majority are solid to semi porous. This type of tap slag was recovered in most locations: 25/01/10 (3) (6), 26/01/10 (7) (8), 28/01/10 (1) (2) (5), 29/01/10 (4), 30/01/10 (1) (2), 01/02/10 (2) (3) (4) (5) (8), 02/02/10 (4) (5) (6) (7) (8), 03/02/10 (1) (6) (9) (12) (13) (14) (15), 05/02/10 (1) (2) (3) (4) (5) (6) (7), 06/02/10 (2), 08/02/10 (1) (2) (10) (11), 09/02/10 (4) (7), 10/02/10 (2) (4), 11/02/10 (1) (2) (5) (6), 12/02/10 (1) A3 C19 (6) (7) (10), 13/02/10 (1) (2) (3) (6) (9) (10) (12) (13) (14) (15), 15/02/10 (1) (2) (3) (4), 16/02/10 (1) (2) (5) (6), 17/02/10 (1) (2) (3), 18/02/10 (1) (2) (4) (5) (7), 19/02/10 (3) (4) (5) (6), 21/02/10 (1) (3) (5) (6), 22/02/10 (1) (4), 23/02/10 (1) (4) (6) (7) (8) (9) (10) (11) (12), 24/02/10 (1) (2) (3), 25/02/10 (1) (2) (3) (4) (5) (7) (8), 26/02/10 (1) (3) (5) (7) (8), 27/02/10 (1) (3) (4) (6), 19/09/09 (6) (9) and 20/09/09 (3).

The majority of the fragments are fully fragmentary with all or most edges broken. This means that they would all have been part of larger flows of tap slag. They vary greatly in size from the smallest fragment being 16mm in length, 16mm in width and 14mm in thickness to the largest fragment being 445mm in length, 264 in width and 76mm in thickness. However, the majority of the tap slag fragments are between 30-180mm in length, 30-120mm in width and 18-55mm in thickness. The main exceptions are a few fragments found in locations 28/01/10 (5), 03/02/10 (9) (15), 05/02/10 (1) (2) (6), 11/02/10 (5), 13/02/10 (1) (14) (15), 15/02/10 (1) (2), 16/02/10 (1), 19/02/10 (4) (6), 22/02/10 (1), 23/02/10 (6) (8) (9) (10) (11) (12), 24/02/10 (1) and 17/02/10 (4). These are much larger than the average being up to 445mm in length, 264mm in width and 104mm thick.

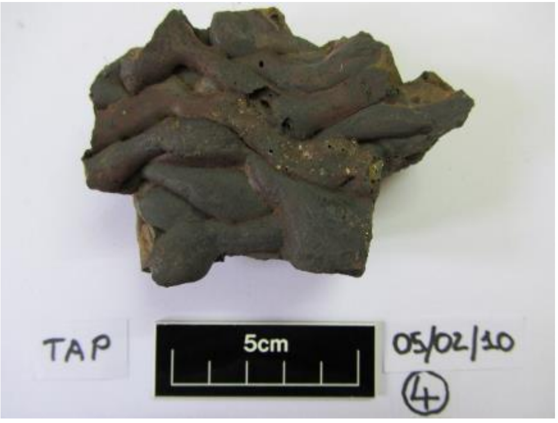
Most fragments are plano-plano in profile with flat top and bottom surfaces but there are variations with more irregular shaped fragments that were shaped by the ground on which they ran over. Some fragments (especially some in locations 25/01/10 (6), 26/01/10 (7), 28/01/10 (5), 01/02/10 (3) (8), 03/02/10 (15), 05/02/10 (1) (6), 11/02/10 (5) (6), 13/02/10 (1) (14) (15), 15/02/10 (1) (2), 16/02/10 (1) (6), 19/02/10 (6), 23/02/10 (8) (9) (11) (12)) have curved or rounded undersides (plano-convex in profile) suggesting that they may have ran into and solidified in a ground depression. Whether or not these ground depressions were dug deliberately to channel the tapped slag away from the furnace is unknown. This is most often seen in larger fragments especially those found in the locations mentioned above. In some instances fragments have uneven bases (and/or top surfaces) sometimes with large stone or charcoal impressions suggesting that the ground around the furnace was uneven or covered in smelting debris. Good examples of these are found in locations 30/01/10 (1) (2), 03/02/10 (6) (12), 05/02/10 (3), 08/02/10 (10), 13/02/10 (12), 15/02/10 (3), 16/02/10 (2), 18/02/10 (4) (5), 19/02/10 (3), 21/02/10 (3), 23/02/10 (10), 24/02/10 (2) (3), 25/02/10 (4), 26/02/10 (1) (3) (7) (8), 19/09/09 (9), 20/09/09 (3). Most edges are broken leaving sharp flat breaks but in some cases one or more edge survives (especially on smaller, thinner flows). These are always rounded and smooth, often part of a ripple which lines the natural edge of the slag. The thicknesses of the larger fragments with curved undersides tapers towards the natural edges.

The main defining feature of this tap slag type are the rippled top surfaces. These are mainly dark greyish blue in colour with patches of varying shades of dark red/purple, brown and sometimes orange. These coloured patches are probably due to the oxidisation of the surface and soil staining which may have occurred after deposition. The surfaces are for the most part smooth with well-rounded or flattened ripples but in some cases the ripples are slightly rougher (low to medium rough) with very small crimples on their surface like the skin on milk (good example in 11/02/10 (1)). The top surfaces probably cooled and hardened faster than the slag below it meaning that if it still flowed beneath the hardening surface it may have caused it to crimple. The surface ripples are between 3-155mm in width with most being between 15-50mm wide. The top surface on some fragments has partially chipped off revealing some spherical and flattened voids underneath.



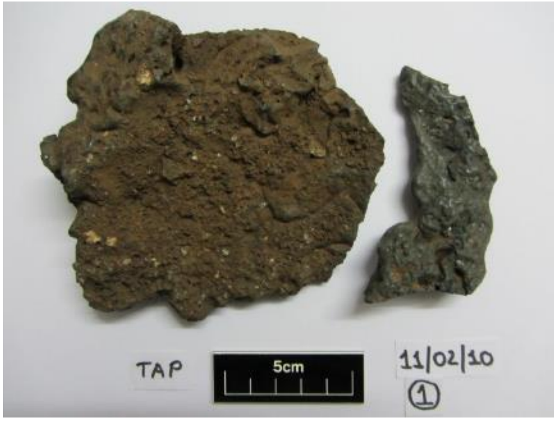


03/02/10 (6)



05/02/10 (4)

10/02/10 (4)



11/02/10 (1)

15/02/10 (1)

17/02/10 (3)


19/02/10 (6)


21/02/10 (6)


23/02/10 (10)


25/02/10 (1)

27/02/10 (3)

28/01/10 (5)

03/02/10 (14)

Some of the fragments from locations 01/02/10 (5), 08/02/10 (1) (2), 16/02/10 (6), 18/02/10 (5), 19/02/10 (6), 23/02/10 (4) (7) (8), 24/02/10 (3) and 26/02/10 (3) (5) (7) have thinner and more defined ripples or flows on the top surfaces (mainly between 8-25mm but as thin as 3mm and as wide as 42mm). Sometimes these tendrils overlap resembling the ropy type 2 tap slag but they have been categorised as type 1 as they are not as ropy and the lower parts (beneath the top surface) of the slags are fully fused (homogenised).


18/02/10 (5)


23/02/10 (4)


26/02/10 (3)


26/02/10 (5)

Some of the larger fragments found in locations 03/02/10 (9) (15), 05/02/10 (1) (6), 11/02/10 (6), 13/02/10 (1) (14) (15), 15/02/10 (1) (2), 16/02/10 (1), 19/02 10 (6) and 23/02/10 (8) (9) (12) have flatter and wider surface ripples indicating that the slag was less viscous. Most of these have curved undersides meaning that they pooled in ground depressions further supporting the idea that they were less viscous. The top surfaces are for the most part solid with very few spherical and globular voids but on some examples the top crust has partially chipped off revealing greater porosity.


03/02/10 (15)


05/02/10 (6)


13/02/10 (1)


13/02/10 (14)


13/02/10 (15)


23/02/10 (9)


23/02/10 (12)

The bottom surfaces are all very similar, mainly being relatively smooth to low rough dominated by very small rounded undulations caused by the slag running over small stones or debris. In many cases small stones and quartz up to 18mm in size (but mostly <5mm) are still embedded in these small undulations. On some fragments there are also small charcoal impressions clearly identifiable by their linear wood grain imprints. These are up to 30mm in size but most are <15mm. They tend to be very light impressions which add to the undulated texture. Most bases are also dark greyish blue in colour with similar coloured patches found on the top surfaces but many have a slight metallic sheen. In some examples, as discussed above, the bases are more uneven with larger depressions left by larger debris (stones/charcoal) and rough ground surfaces. Most of these surfaces still have the smooth undulations but some can be rougher in texture with larger and sharper protrusions caused by the voids and indentations created by ground debris (like in fragments from 28/01/10 (1), 15/02/10 (3), 16/02/10 (2) and 26/02/10 (1)).

15/02/10 (3)

16/02/10 (2)

26/02/10 (1)

Also, in some cases the slags appear to have run over loose soil as there are remains of gritty soil material adhering or fused to the bases with many small stones or quartz. These are mid rough (coarse sandpaper rough and sometimes friable) in texture, usually varying in shades of brown, red and yellowy orange. Good examples of these are found in locations 25/01/10 (6), 01/02/10 (4) (8), 03/02/10 (14), 13/02/10 (14), 15/02/10 (1) (2), 16/02/10 (1) (5), 19/02/10 (5), 23/02/10 (8) (9) (12), 24/02/10 (1) and 25/02/10 (7). All bottom surfaces are solid with very few or no voids.

01/02/10 (4)

15/02/10 (1)

16/02/10 (1)

23/02/10 (8)


24/02/10 (1)


25/02/10 (7)

As most fragments are fully fragmentary the edges are broken showing good cross sections. This shows that the majority of the type 1 tap slag fragments are solid to semi-porous with relatively few voids. Most of these voids are spherical or globular up to 27mm in size but mainly between 2-12mm. There are also some elongated or flattened voids (mainly horizontal – linear to the surfaces) up to 170mm in size but mostly less than 60mm. The majority of the porosity is situated in the top half of the fragments with most voids concentrating near or just underneath the top surface. There are a few exceptions that are porous to very porous and these are found in locations 01/02/10 (3), 03/02/10 (15), 05/02/10 (3), 13/02/10 (12), 16/02/10 (2) (6) and 26/02/10 (3).



01/02/10 (3)



05/02/10 (3)



13/02/10 (12)

The fractures also reveal that most tap slag fragments are homogenous in section and primarily dull in colour but some in locations 25/01/10 (6), 28/01/10 (1), 29/01/10 (4), 03/02/10 (9) (14) (15), 05/02/10 (1) (2) (3) (4) (5) (6) (7), 11/02/10 (6), 12/02/10 (6), 13/02/10 (1) (2) (6) (9), 15/02/10 (1) (2), 17/02/10 (2), 18/02/10 (2), 21/02/10 (1), 22/02/10 (4), 23/02/10 (1) (6) (8) (11) (12), 24/02/10 (1), 25/02/10 (2) (8), 27/02/10 (6) and 19/09/09 (6) have shiny sometimes heavily crystallised surfaces with large fayalite crystals dominating their surfaces or fractures. This is undoubtedly due to the slow cooling rate of the slag allowing time for large spinels to grow before solidification. The crystallisation appears to occur mainly on larger or thicker fragments, not surprising as they would have taken longer to cool.

05/02/10 (1)

13/02/10 (9)

23/02/10 (8)

23/02/10 (12)

25/02/10 (8)

19/09/09 (6)

Although the majority of the fragments are of a dark greyish-blue colour some fragments also have tints of pale or dark pastel green usually covering part or the whole of the bottom surface (in a few cases there is some green on the top surface). These are prominent in locations 28/01/10 (1) (2), 30/01/10 (1), 02/02/10 (6), 03/02/10 (12), 09/02/10 (7), 11/02/10 (2), 13/02/10 (3), 19/02/10 (5) and 23/02/10 (1). This suggests that heavy melting of the furnace walls (technical ceramics) occurred which subsequently contributed to a significant proportion of the slag composition. None of the tap slag fragments are magnetic, however, a few examples in locations 30/01/10 (2), 05/02/10 (2) and 16/02/10 (5) have small magnetic patches where there must be a greater concentration of metallic iron. The fragment in 05/02/10 (2) has a small magnetic lump about 10mm in size. Most of these areas are of a dark reddish purple or orangey yellowy brown colour.

09/02/10 (7)

13/02/10 (3)

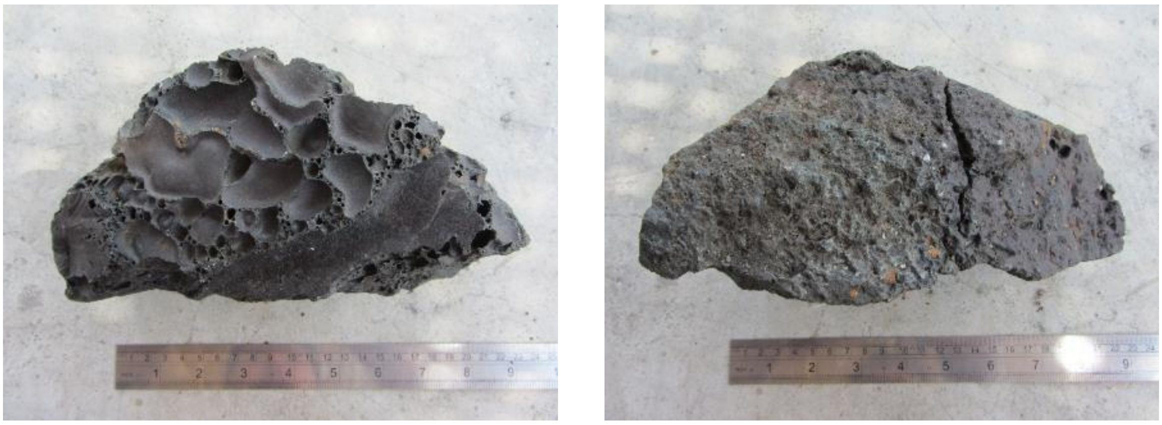
23/02/10 (1)

Appendix C.1.2 – TS1.1

Characteristic features	Mostly large solid cakes; top surfaces broken revealing more porosity below surface, crystallisation common
Size range	Wide range of sizes from the smallest fragment 32mm in length, 18mm in width and 27mm in thickness to the largest fragment 301mm in length, 198mm in width and 72mm in thickness. The thickness of some of the larger fragments can be up to 112mm.
Locations in which found	28/01/10 (5), 29/01/10 (1) (3) (4) (5), 30/01/10 (2), 01/02/10 (1) (7) (8), 02/02/10 (6) (7), 03/02/10 (1) (3) (4) (6) (9) (10) (11) (12) (13) (15), 05/02/10 (2) (3) (5) (7), 06/02/10 (2) (3), 08/02/10 (9) (10), 09/02/10 (7), 11/02/10 (2), 13/02/10 (1) (2) (6) (7) (8) (9) (10) (11), 16/02/10 (1) (5) (6), 17/02/10 (1) (2) (4), 18/02/10 (1) (2), 19/02/10 (1) (3) (4) (6), 21/02/10 (1) (3) (4) (7), 22/02/10 (1) (4), 23/02/10 (2) (3) (6), 24/02/10 (2) (3) (4), 25/02/10 (5) (7), 26/02/10 (1) (3) (4) (5), 27/02/10 (6) (7)

This type is the second most common tap slag type. No fragments survive whole but the bottom surfaces are intact indicating that they were indeed slag that ran out of a furnace (tap slag). They are very similar to the type 1 examples discussed above but their main characteristic feature is that the top surfaces are missing (meaning that they cannot be attributed to type 1). Most are solid with greater porosity where the top surface has broken off, greyish blue in colour and many have a shiny crystallised structure. This type of tap slag is found in locations 28/01/10 (5), 29/01/10 (1) (3) (4) (5), 30/01/10 (2), 01/02/10 (1) (7) (8), 02/02/10 (6) (7), 03/02/10 (1) (3) (4) (6) (9) (10) (11) (12) (13) (15), 05/02/10 (2) (3) (5) (7), 06/02/10 (2) (3), 08/02/10 (9) (10), 09/02/10 (7), 11/02/10 (2), 13/02/10 (1) (2) (6) (7) (8) (9) (10) (11), 16/02/10 (1) (5) (6), 17/02/10 (1) (2) (4), 18/02/10 (1) (2), 19/02/10 (1) (3) (4) (6), 21/02/10 (1) (3) (4) (7), 22/02/10 (1) (4), 23/02/10 (2) (3) (6), 24/02/10 (2) (3) (4), 25/02/10 (5) (7), 26/02/10 (1) (3) (4) (5), 27/02/10 (6) (7).

The fragments of this type vary in size and shape and most seem to have been part of much larger runs of slag. They vary in size from the smallest fragment 32mm in length, 18mm in width and 27mm in thickness to the largest fragment 301mm in length, 198mm in width and 72mm in thickness. The thickness of some of the larger fragments can be up to 112mm. However, most fragments are between 40-135mm in length, 35-95mm in width and 35-65mm in thickness. Some of the largest fragments are found in locations 03/02/10 (10) (13), 05/02/10 (2), 13/02/10 (1) and 19/02/10 (4) (6). Like the type 1 examples, the majority are plano-plano in profile with flat top and bottom surfaces. This is especially true of the smaller fragments, but some have curved or rounded undersides suggesting that they may have run and solidified in a ground depression. These are found in locations 03/02/10 (10) (11) (13), 08/02/10 (9), 13/02/10 (1) (7) (11), 16/02/10 (6), 24/02/10 (4) and 25/02/10 (7).



03/02/10 (10)

03/02/10 (13)

13/02/10 (1)

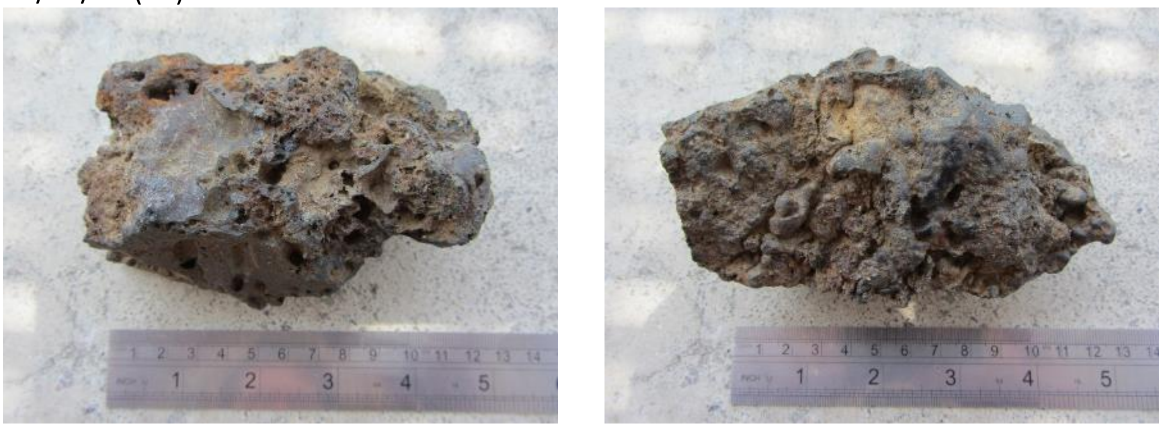
24/02/10 (4)

Some also have uneven or bottom surfaces shaped by the ground on which they ran over and solidified. Sometimes there are large impressions of charcoal or stones. Good examples with uneven bases are found in locations 03/02/10 (13), 13/02/10 (7) (11), 21/02/10 (3), 23/02/10 (2) and 17/02/10 (4). All fragments have broken edges with none or very few with remaining rounded natural edges. These breaks are usually clean, sharp and angular.

03/02/10 (13)

13/02/10 (7)

13/02/10 (11)



23/02/10 (2)

The main defining feature of this tap slag type are the broken top surfaces. These are usually smooth for the most part with small projections of broken material that are sharp and angular. These must have been where the top surfaces were attached to the rest of the slag. The smooth, flat parts which dominate the top surfaces are the bottom of large globular, flattened voids surrounded by the broken projections (often with scatters of smaller spherical voids) where the top surface would have been attached. Some of these projections still have very small remains of the original top surfaces (especially on some of the edges or in between larger voids) suggesting that the porosity would have been present just below the top. These large voids undoubtedly created a weakness which caused the slag to break after deposition. The slags are mostly greyish blue in colour but unlike the type 1 examples many have a shiny crystallised sheen. This may be due to the fact that most of the type 1.1 fragments are larger and must have taken more time to cool allowing crystals to grow before solidification. It may also be because the top surfaces are missing and more of the interior of the slag can be seen. Nevertheless, most also have similar coloured patches found on the type 1 examples. These patches or tints are mainly dark red or brown but vary in shades of dark red/purple, brown and sometimes orange. Most are likely due to oxidisation and soil staining which may have occurred after deposition. Few fragments are rougher on the top surfaces with smaller spherical voids dominating the broken surface leaving a greater percentage of small sharp projections. Some are also dominated by very sharp, angular projections making the top surfaces uneven and rough to the touch. Most of the tap slag of this type likely had smooth rippled top surfaces like the type 1 slags discussed above but some of the more agitated and rough ones may have had crimpled top surfaces like the type 1.2 slags.

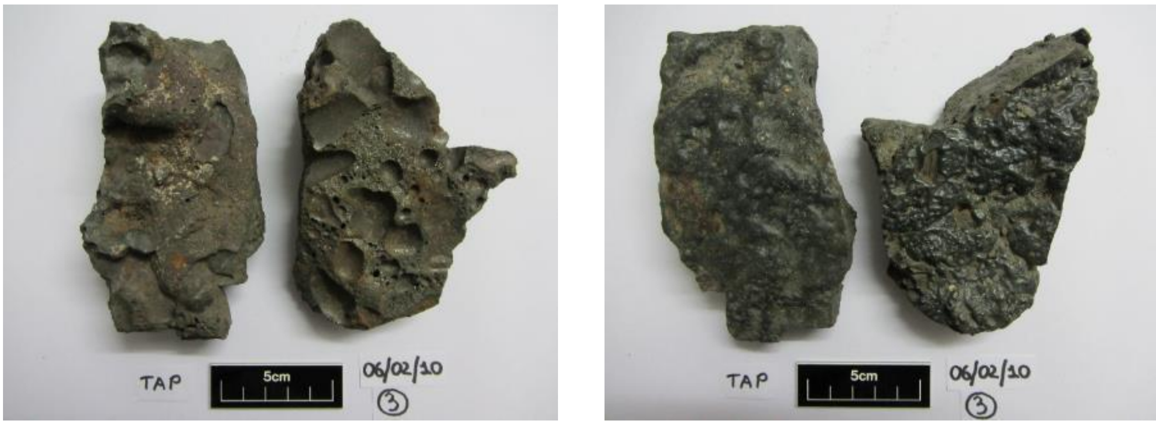
The bottom surfaces are very similar to the type 1 examples, mainly being relatively smooth to low rough dominated by very small rounded undulations caused by the slag running over small stones or debris. In many cases small stones and quartz up to 21mm in size (but mostly <6mm) are still embedded in these small undulations. On some fragments there are also small charcoal impressions clearly identifiable by their linear wood grain imprints. These are up to 26mm in size but most are <12mm. They tend to be very light impressions which add to the undulated texture. Most bases are also dark greyish blue in colour with similar coloured patches found on the top surfaces but many have a slight metallic sheen. In some examples, as discussed above, the bases are more uneven with larger depressions left by larger debris (stones/charcoal) and rough ground surfaces. Most of these surfaces still have the smooth undulations but some can be rougher in texture with larger and sharper protrusions caused by the voids and indentations created by ground debris.

29/01/10 (3)

30/01/10 (2)

03/02/10 (1)

03/02/10 (3)



06/02/10 (3)

17/02/10 (4)


22/02/10 (4)


23/02/10 (3)


26/02/10 (4)


27/02/10 (7)


03/02/10 (15)

Also, in some cases the slags (like the type 1 examples) appear to have run over loose soil as there are remains of gritty soil material adhering or fused to the bases with many small stones or quartz. These are mid rough (coarse sandpaper rough and sometimes friable) in texture, usually varying in shades of brown, red and yellowy orange. Good examples of these are found in locations 02/02/10 (7), 03/02/10 (13) (15), 05/02/10 (2), 09/02/10 (7), 13/02/10 (1), 19/02/10 (3), 25/02/10 (7) and 26/02/10 (5). All bottom surfaces are solid with very few or no voids.


02/02/10 (7)


25/02/10 (7)


03/02/10 (15)

19/02/10 (3)

As most fragments are fully fragmentary the edges are broken showing good cross sections. This shows that the majority of the type 1.1 tap slag fragments are solid with relatively few voids. There is greater porosity (up to semi-porous) closer to the top surface but most only have the remains of the large globular flattened voids on their top surfaces. Most of these voids are spherical or globular up to 30mm in size but mainly between 2-15mm. The more elongated/flattened voids on the top surfaces are up to 170mm in size but mostly <65mm. Some of the fragments from 01/02/10 (1) have more porosity being porous on the top half of the slag.

The fractures also reveal that most tap slag fragments are homogenous in section. Some are dull in colour but the majority have shiny, sometimes heavily crystallised surfaces. These are found in locations 28/01/10 (5), 29/01/10 (1) (3) (4), 30/01/10 (2), 01/02/10 (1), 02/02/10 (6), 03/02/10 (1) (4) (6) (10) (11) (12) (13) (15), 05/02/10 (2) (3) (5) (7), 06/02/10 (2) (3), 08/02/10 (9) (10), 09/02/10 (7), 11/02/10 (2), 13/02/10 (1) (2) (6) (9), 16/02/10 (1), 17/02/10 (1) (2), 18/02/10 (2), 21/02/10 (1), 22/02/10 (1) (4), 23/02/10 (3) (6), 24/02/10 (4), 25/02/10 (7), 26/02/10 (5) and 27/02/10 (6). Some of the fragments in locations 03/02/10 (11) (13) (15), 05/02/10 (2), 09/02/10 (7), 11/02/10 (2), 13/02/10 (1) (6) (9), 16/02/10 (1), 23/02/10 (3), 24/02/10 (4), 25/02/10 (7) and 26/02/10 (5) are particularly crystallised with large fayalite crystals dominating their structure. Sometimes this crystallisation is also noticeable on the broken top surfaces producing very rough sharp textures whereby the small crystals project from the main body of the slag. In these cases, elongated and angular voids are common between the individual or grouped crystals. On others the crystals are flush with the flat surfaces created by the flattened voids. This is undoubtedly due to the slow cooling rate of the slag allowing time for large spinels to grow before solidification. The crystallisation appears to occur mainly on larger or thicker fragments, not surprising as they would have taken longer to cool.

03/02/10 (15)

05/02/10 (2)


09/02/10 (7)

16/02/10 (1)


26/02/10 (5)

Appendix C.1.3 – TS1.2

Characteristic features	Rough crimpled top surface; undulated bottom surface; dark greyish blue with patches of varying shades of dark red/purple, brown and orange/yellow
Size range	Wide range of sizes from the smallest fragment 46mm in length, 38mm in width and 23mm in thickness to the largest fragment 222mm in length, 146mm in width and 73mm in thickness. The thickness of some of the larger fragments can be up to 95mm.
Locations in which found	28/01/10 (5), 01/02/10 (7) (8), 02/02/10 (1), 03/02/10 (3) (4) (9) (10) (14) (15), 11/02/10 (5), 12/02/10 (8), 13/02/10 (13), 17/02/10 (3), 18/02/10 (1) (2), 22/02/10 (3) (4), 24/02/10 (1), 27/02/10 (4) (7), 19/09/09 (9)

There are few tap slag fragments of this type in the assemblage. The fragments are all fragmentary with none surviving whole but the majority have surviving top and bottom surfaces. They all vary in shape and size but the major characteristic features which define this tap slag type are their crimpled, rough top surfaces, undulated bottom surfaces; dark greyish blue colour often with patches varying in shades of dark red/purple, brown, yellow and orange as well as their varying degrees of porosity. This type of tap slag was recovered in locations: 28/01/10 (5), 01/02/10 (7) (8), 02/02/10 (1), 03/02/10 (3) (4) (9) (10) (14) (15), 11/02/10 (5), 12/02/10 (8), 13/02/10 (13), 17/02/10 (3), 18/02/10 (1) (2), 22/02/10 (3) (4), 24/02/10 (1), 27/02/10 (4) (7) and 19/09/09 (9).

The majority of the fragments are fully fragmentary with all or most edges broken. This means that they would all have been part of larger flows of tap slag. They vary greatly in size from the smallest fragment being 46mm in length, 38mm in width and 23mm in thickness to the largest fragment being 222mm in length, 146mm in width and 73mm in thickness. The larger fragments are up to 95mm thick. However, the majority of the type 1.2 tap slag fragments are between 65-155mm in length, 38-110mm in width and 30-50-mm in thickness. Some large fragments were recovered from locations 02/02/10 (1), 03/02/10 (3) (4) (9) (14), 18/02/10 (1) and 27/02/10 (4).

Like the type 1 and 1.1 slags most fragments are plano-plano in profile with flat top and bottom surfaces but there are variations with more irregular shaped fragments that were shaped by the ground on which they ran over. Some fragments (especially some in locations

01/02/10 (8), 03/02/10 (10), (14), 11/02/10 (5) and 18/02/10 (2)) have curved or rounded undersides (plano-convex in profile) suggesting that they may have ran into and solidified in a ground depression.

03/02/10 (14)

03/02/10 (10)

In some instances fragments have uneven bases (and/or top surfaces) sometimes with large stone or charcoal impressions suggesting that the ground around the furnace was uneven or covered in smelting debris. Good examples of these are found in locations 02/02/10 (1), 03/02/10 (3) (9) (10), 12/02/10 (8), 22/02/10 (2) and 24/02/10 (1). Most edges are broken leaving sharp flat breaks but in some cases one or more edge survives (especially on smaller, thinner flows). These are always rounded and smooth, often part of a ripple which lines the natural edge of the slag. The thicknesses of the larger fragments with curved undersides tapers towards the natural edges.

03/02/10 (9)

12/02/10 (8)

The main defining feature of this slag type are their rough agitated top surfaces. These are mainly dark grey to dark greyish blue in colour but most also have coloured patches. These patches are often a mixture of dark red and brown shades but in some cases also shades of orangey brown. These coloured patches are probably due to the oxidisation of the surface and soil staining which may have occurred after deposition. The top surfaces are for the most part rough to very rough in texture dominated by agitated crimples of slag (like the skin on milk). The very top layer of the slag appears to have bunched together forming linear folds (usually perpendicular to the flow of the slag). This may have happened as the top surface likely cooled and started solidifying faster than the slag below it meaning that the lower layers of slag may have carried on flowing beneath the top hardening (but still malleable) crust and causing it to crimple. In most cases these crimples are broken (probably caused after deposition) leaving small sharp projections of broken slag and often revealing many small spherical or globular voids beneath the surface (making them porous). These add to the rough texture of the surface. The only exceptions where the surface crimples remain mostly intact are found in locations 18/02/10 (1) (2) and 22/02/10 (3). On most examples there are also some small stone or quartz inclusions (mostly <5mm) still embedded in the top surface. Some also display a grittier medium to coarse sandpaper rough texture which is sometime friable suggesting that these fragments may have been covered in soil while they were still flowing (especially fragments in locations 01/02/10 (7) and 03/02/10 (15)). This may have been done to reduce some of the heat emanating from the flowing slag allowing the smelters to get closer to the furnace. It could also explain the crimples and greater porosity in the top part of the slags as the soil would have created surface tension (friction) on the top surfaces perhaps causing them to crimple and trapping more gas voids.


03/02/10 (4)

11/02/10 (5)

27/02/10 (4)

18/02/10 (1)

The bottom surfaces are all very similar, mainly being relatively smooth to low rough dominated by very small rounded undulations caused by the slag running over small stones or debris. In many cases small stones and quartz up to 18mm in size (but mostly <5mm) are still embedded in these small undulations. On some fragments there are also small charcoal impressions clearly identifiable by their linear wood grain imprints. These are up to 40mm in size but most are <15mm. They tend to be very light impressions which add to the undulated texture. Most bases are also dark grey or dark greyish blue in colour with similar coloured patches found on the top surfaces but some have a slight metallic sheen. In some examples, as discussed above, the bases are more uneven with larger depressions left by larger debris (stones/charcoal) and rough ground surfaces. Most of these surfaces still have the smooth undulations but some can be rougher in texture with larger and sharper protrusions caused by the voids and indentations created by ground debris. Also, in some cases the slags appear to have run over loose soil as there are remains of gritty soil material adhering or fused to the bases with many small stones or quartz. These are mid rough (coarse sandpaper rough and sometimes friable) in texture, usually varying in shades of brown, red and yellowy orange. Good examples of these are found in locations 01/02/10 (7) (8) and 03/02/10 (3). All bottom surfaces are solid with very few or no voids.

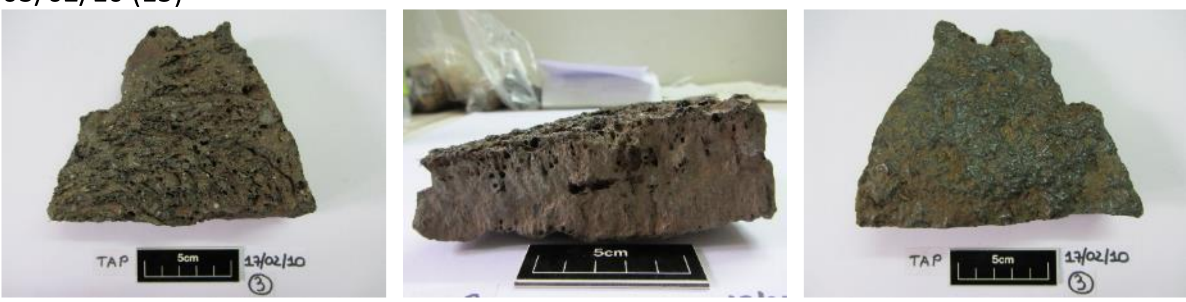
01/02/10 (8)

03/02/10 (3)

As most fragments are fully fragmentary, the edges are broken showing good cross sections. This shows that the type 1.2 tap slag fragments vary significantly in porosity. Most are solid to semi-porous with relatively few voids but some of the fragments found in locations 03/02/10 (14) (15), 12/02/10 (8) and 27/02/10 (4) (7) are porous to very porous in nature (some only in parts – usually the top half is more porous). Most of these voids are spherical or globular up to 25mm in size but mainly between 2-12mm. There are also some elongated or flattened voids (mainly horizontal – linear to the surfaces) up to 85mm in size but mostly less than 50mm. In many cases the porosity is situated in the top half of the fragments with most voids concentrating near or just underneath the top surface meaning that some of the slags may have a solid bottom part but a semi to porous upper part.

The fractures also reveal that most tap slag fragments are homogenous in section and primarily dull in colour but some in locations 28/01/10 (5), 03/02/10 (10) (14) (15), 11/02/10 (5), 17/02/10 (3), 18/02/10 (1) and 22/02/10 (4) have shiny sometimes heavily crystallised surfaces. This is undoubtedly due to the slow cooling rate of the slag allowing time for large spinels to grow before solidification. The crystallisation appears to occur mainly on larger or thicker fragments, not surprising as they would have taken longer to cool. If these slags were covered in soil while still hot or flowing this would also have slowed the cooling rate.

03/02/10 (15)



22/02/10 (4)

28/01/10 (5)

All type 1.2 tap slag fragments are of a dark greyish blue colour but the fragment from 27/02/10 (4) also has tints of pale or dark pastel green covering part of its bottom surface. This suggests that heavy melting of the furnace walls (technical ceramics) occurred which subsequently contributed to a significant proportion of the slag composition. None of the tap slag fragments are magnetic, however, a few have small magnetic patches where there must be a greater concentration of metallic iron. Most of these areas are of a dark reddish purple or orangey yellowy brown colour.

Appendix C.1.4 – TS2

Characteristic features	Ropey top surface made of amalgamation of slag tendrils; usually quite thin but some large cakes; mostly semi-porous; dark greyish blue in colour with patches of varying shades of dark red/purple, brown and yellowy orange
Size range	Wide range of sizes from the smallest fragment 20mm in length, 18mm in width and 6mm in thickness to the largest fragment 238mm in length, 213mm in width and 93mm in thickness. The thickness of some of the larger fragments can be up to 113mm.
Locations in which found	28/01/10 (1), 29/01/10 (1) (3), 01/02/10 (1) (5), 02/02/10 (6), 03/02/10 (3) (4), 08/02/10 (1) (4) (5) (9) (10), 09/02/10 (1) (2) (5), 10/02/10 (1), 12/02/10 (1) A8, 13/02/10 (7), 16/02/10 (1) (2), 18/02/10 (3) (6), 19/02/10 (1) (2) (3) (4) (6), 22/02/10 (1) (3), 23/02/10 (2) (3) (5) (9), 24/02/10 (1) (3) (4), 25/02/10 (8), 27/02/10 (6) (7)

Material fragments of this type are the third most abundant tap slag type in the assemblage. The fragments are all fragmentary with none surviving whole but the top and bottom surfaces survive. Their major characteristic features are their ropey top surfaces made of an amalgamation of slag tendrils; they are usually quite thin but there are some larger cakes; they are mostly semi-porous in nature and are dark greyish blue in colour with patches of varying shades of dark red/purple, brown and yellowy orange. This type of tap slag was recovered in locations: 28/01/10 (1), 29/01/10 (1) (3), 01/02/10 (1) (5), 02/02/10 (6), 03/02/10 (3) (4), 08/02/10 (1) (4) (5) (9) (10), 09/02/10 (1) (2) (5), 10/02/10 (1), 12/02/10 (1) A8, 13/02/10 (7), 16/02/10 (1) (2), 18/02/10 (3) (6), 19/02/10 (1) (2) (3) (4) (6), 22/02/10 (1) (3), 23/02/10 (2) (3) (5) (9), 24/02/10 (1) (3) (4), 25/02/10 (8), 27/02/10 (6) (7).

The majority of the fragments are fully fragmentary with all or most edges broken. This means that they would all have been part of larger flows of tap slag. They vary greatly in size from the smallest fragment being 20mm in length, 18mm in width and 6mm in thickness to the largest fragment being 238mm in length, 213mm in width and 93mm in thickness. The larger fragments are up to 113mm thick. However, the majority of the type 2 tap slag fragments are between 40-130mm in length, 20-105mm in width and 11-55mm in thickness. Some large fragments were recovered from locations 29/01/10 (1), 01/02/10 (1) (5), 08/02/10 (10), 09/02/10 (5), 19/02/10 (1) (2), 23/02/10 (3) and 27/02/10 (7).

Like the type 1, 1.1 and 1.2 slags most fragments are plano-plano in profile with reasonably flat top and bottom surfaces but there are variations with more irregular shaped fragments that were shaped by the ground on which they ran over. Some fragments (especially some in locations 29/01/10 (1), 01/02/10 (1) (5), 08/02/10 (9) (10), 09/02/10 (5), 18/02/10 (3), 19/02/10 (1) and 23/02/10 (5) have curved or rounded undersides (plano-convex in profile) suggesting that they may have ran into and solidified in a ground depression. In addition, since all fragments of this type are an amalgamation of slag tendrils their top surfaces are rarely completely flat but covered in rounded and overlapping trickles of slag. Most edges are broken leaving sharp flat or stepped breaks but in some cases one or more edge survives (especially on smaller, thinner flows). These are always rounded and smooth, often part of a tendril/trickle which lines the natural edge of the slag.


29/01/10 (1)


08/02/10 (10)

19/02/10 (1)

23/02/10 (5)

The main defining feature of this slag type are their generally smooth ropey top surfaces. The slag fragments appear to have been formed by the amalgamation of slag trickles which have fused/adhered together to make larger slag cakes. These slag tendrils range in width from 4 to 40mm but most are between 8 and 20mm. The top surfaces are generally uneven due to the presence of overlapping and layered slag tendrils but the smaller and thinner fragments are flatter as the slag trickles seem to have run parallel and hence overlapped less. The slag trickles on most fragments appear to have flown in the same direction and some of the larger/thicker fragments have many layers whereby slag flows ran on top of previous flows. All top surfaces are of a dull dark greyish blue colour but most fragments also have small patches of varying shades of dark red/purple and yellowy orangey brown. The top surfaces are almost always smooth but there are some fragments with more agitated surfaces. These either have slight crimpling of the top crust (like the skin on milk) or broken section which have left small, sharp protrusions (good examples in locations 09/02/10 (2), 22/02/10 (1) and 27/02/10 (7)). The majority of the top surfaces are solid with no or very few globular or spherical voids. These slags must have been very viscous perhaps because the technology used to produce iron was not very efficient or they could have been allowed out of the furnace in the early stages of the smelting process when it may not have been running at optimum condition.


28/01/10 (1)


01/02/10 (1)

13/02/10 (7)

16/02/10 (2)

25/02/10 (8)

27/02/10 (6)

The bottom surfaces seem much more uneven for the most part than other types of tap slag. Some are relatively smooth to low rough dominated by very small rounded undulations caused by the slag running over small stones or debris. These tend to be dark greyish blue or dark grey in colour sometimes with a shiny surface. Most examples however, are more uneven with larger depressions left by larger debris (stones/charcoal) and rough ground surfaces. Most of these surfaces still have some smooth undulations but in many cases they are rougher in texture with larger and sharper protrusions caused by the voids and indentations created by ground debris. Small stones and quartz up to 12mm in size (but mostly <5mm) are sometimes still embedded in these undulations. On some fragments there are also charcoal impressions and voids clearly identifiable by their linear wood grain imprints. These are up to 30mm in size but most are <15mm. These bases are also dark grey or dark greyish blue in colour but are dominated by large coloured patches of varying shades of dark red/purple, brown, orange and yellow. Good examples of slags with uneven bases are found in locations 29/01/10 (1) (3), 03/02/10 (3) (4), 08/02/10 (1) (4) (5) (9) (10), 09/02/10 (1) (2), 16/02/10 (1), 18/02/10 (3) (6), 19/02/10 (3), 22/02/10 (3), 23/02/10 (2) (3) (5) (9) and 24/02/10 (4). The flattened undersides of individual tendrils that have amalgamated can also be seen on most bottom surfaces. These mostly run parallel (sometimes meandering probably following the lay of the ground) and the slightly rounded edges of each tendril can clearly be seen forming small curved, linear indentations where they are fused with other tendrils. In some cases they overlap but are still flattened due to running over a hard surface.


29/01/10 (1)

29/02/10 (3)

03/02/10 (4)

08/02/10 (1)

08/02/10 (5)


08/02/10 (9)


18/02/10 (3)


19/02/10 (3)


23/02/10 (3)

Also, in some cases the slags appear to have run over loose soil as there are remains of gritty soil material adhering or fused to the bases with many small stones or quartz. These are mid rough (coarse sandpaper rough and sometimes friable) in texture, usually varying in shades of brown, red and yellowy orange. Good examples of these are found in locations 01/02/10 (1), 02/02/10 (6), 08/02/10 (1), 09/02/10 (2), 19/02/10 (2), 23/02/10 (5), 24/02/10 (1) and 27/02/10 (7). All bottom surfaces are solid with very few (sometime with very small spherical voids where the slag has been abraded) or no voids.

19/02/10 (2)

24/02/10 (1)

27/02/10 (7)

09/02/10 (2)

As most fragments are fully fragmentary, the edges are broken showing good cross sections. This shows that the type 2 tap slag fragments are mostly semi-porous. Most of the smaller fragments are solid to low in porosity but there are some fragments (in locations 08/02/10 (4) (10), 12/02/10 (1) and 18/02/10 (6)) which are semi porous to porous in nature. Most of the voids are spherical or globular up to 19mm in size but mainly between 2-12mm. In a few examples from locations 29/01/10 (1) (3), 01/02/10 (1), 02/02/10 (6), 09/02/10 (9), 12/02/10 (1) and 23/02/10 (9) there are some (but few) elongated or flattened voids (mainly horizontal – linear to the surfaces) up to 47mm in size but mostly less than 30mm. Unlike all other tap slag types where the majority of the porosity is situated in the top half of the fragments, the type 2 slags have much more random porosity usually spread evenly throughout the section. This may be partially due to the fact that some fragments have stepped fractures caused by the different layers of slag trickles with some porosity apparent in between these.

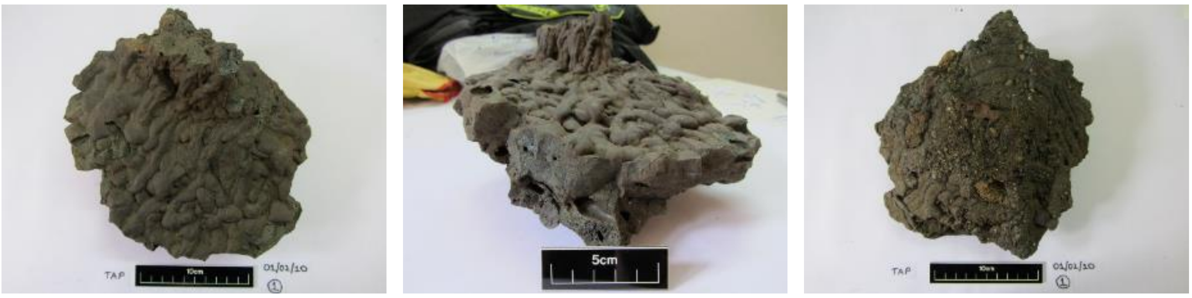
18/02/10 (6)

The fractures also reveal that all tap slag fragments are homogenous in section being dull dark greyish blue in colour. Unlike the other tap slag types, there are no fragments displaying a shiny crystallised structure. On the other hand, a few fragments from locations 29/02/10 (1) (3), 03/02/10 (4), 08/02/10 (4) (10), 13/02/10 (7), 19/02/10 (4) and 27/02/10 (6) do have tints of pale or dark pastel green covering part of their bottom surfaces. This suggests that heavy melting of the furnace walls (technical ceramics) occurred which subsequently contributed to a significant proportion of the slag compositions. The fragments from 09/02/10 (1) are also slightly different. They are black and shiny in some parts. None of the tap slag fragments are magnetic, however, a few have small magnetic patches where there must be a greater concentration of metallic iron. Most of these areas are of a dark reddish purple or orangey yellowy brown colour. A good example is found in location 23/02/10 (2) where there is a large magnetic, dark red patch on the base.

08/02/10 (4)

08/02/10 (10)

Some of the type 2 tap slag fragments have unique features which should be described in more detail. The largest fragment from location 01/02/10 (1) is 205x161x80mm in size and has many of the general features typical of type 2 tap slags with amalgamated greyish blue slag tendrils flowing in the same direction. The tendrils seem to overlap one another and are by majority <10mm wide meaning that it was of medium to high viscosity. Of special interest is the projection of tendrils (rising up to 35mm above the top surface) on one side of the fragment which seem to flow into the cake. This is undoubtedly the slag running out of the furnace into a depression in the ground. This is supported by the curved/rounded bottom surface which has the same tendrils seen on the top surface. These ripples almost seem to be in concentric circles which means that the slag is formed of many layers of slag that have run on previous trickles and flows of slag (following the curvature of the depression). In some areas small undulations are apparent on slag base with a dark blue sheen and in the centre of the underside there are remains of reduced clay. These are likely to be fragments from the furnace wall that have broken off when the furnace was opened. The clay material is coarse with medium to large quartz or stone inclusions. This is very similar to the clay lining also found at this location and the other locations close by. For the most part the slag appears to have solidified on loose soil as there are many small stones still embedded but whether or not it was intentionally directed into a ground depression cannot be ascertained. The cake is broken on about two thirds of its periphery. These reveal that the slag is quite solid with very few tiny spherical holes (<2mm) but a bit more porous closer to the bottom surface with large elongated (horizontal) holes up to 30mm in length.



01/02/10 (1)

A similar fragment was recovered from location 01/02/10 (5). It is 244x173x105mm in size and made of similar small trickles of slag. It is broken on all sides meaning that it would have been larger. The interesting feature of this fragment is that two large projections of slag (also made of an amalgamation of tendrils) rise from the centre of the cake. The flow of the slag is vertical where the large projections are but then the flow appears to spread in all directions around these. This suggests that the slag dribbled into a ground depression from where the slag tendrils fanned out into it. The base is curved and undulated and the individual slag trickles are clearly visible.

01/02/10 (5)

Another fragment of interest from location 08/02/10 (9) deserves more description. It is 245x113x70mm in size (although the majority of the cake is thinner around 25mm) and it looks like the start of an elongated slag run. One end is thicker and more agitated, being made of very rough/sharp, porous slag with large charcoal impressions (up to 30mm). This looks like furnace slag and about 60mm from that end, the slag gets smoother and thins out turning to the typical surface of type 2 tap slag with well-formed overlapping tendrils. The two sides of the cake seem reasonably intact with the slag being broken at both ends. A further point of interest is that it has a rounded bottom perpendicular to the flow meaning that it was probably channelled out of the furnace in a purposely built ground depression (channel). The underside is rough as it probably solidified on loose soil. There are charcoal impressions on the bottom surface (mainly <10mm) but these are more numerous on the rough (furnace slag) end of the cake and get less numerous further down the slag flow. The charcoal on the underside seems to have been mostly fines but there are a few larger impressions up to 20mm. The fragment is semi porous with random scatters of small spherical and globular voids.



08/02/10 (9)

Appendix C.1.5 – TS3

Characteristic features	Slag run in a purposely made channel with curved underside; sometimes covered by soil making top surface coarse sandpaper rough.
Size range	Wide range of sizes from the smallest fragment 29mm in length, 28mm in width and 24mm in thickness to the largest fragment 243mm in length, 139mm in width and 78mm in thickness. The thickness of some of the larger fragments can be up to 86mm.
Locations in which found	25/01/10 (6), 26/01/10 (7), 01/02/10 (4) (5) (8), 02/02/10 (8), 03/02/10 (15), 08/02/10 (9), 09/02/10 (6), 11/02/10 (5), 12/02/10 (1) A3 C19, 13/02/10 (1), 19/02/10 (1), 23/02/10 (5), 26/02/10 (7), 27/02/10 (4)

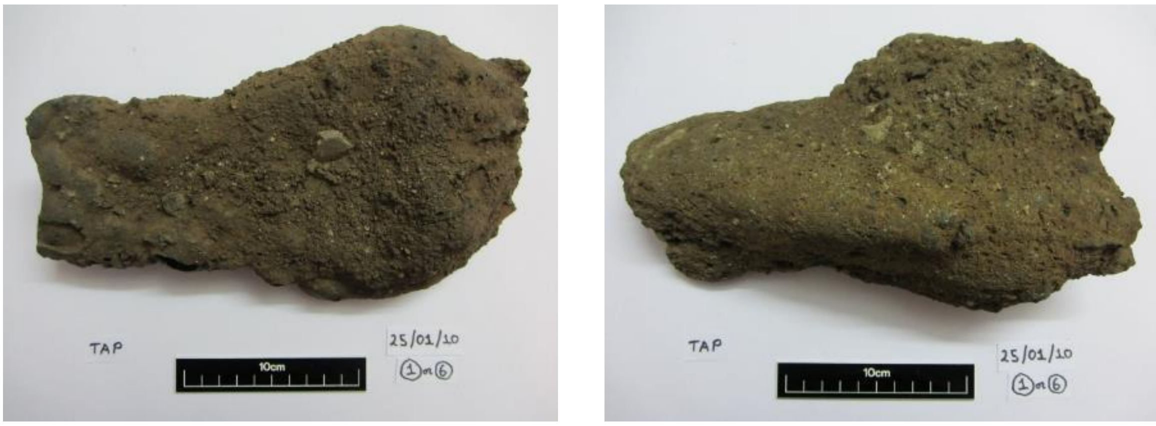
Slags of this type are the least common in the assemblage. All fragments are broken meaning that they would have been part of larger runs of slag. The main characteristic features of this slag type are their curved undersides perpendicular to the flow of the slag, their coarse sandpaper rough top surfaces, their dark grey to dark greyish blue colour often with patches varying in shades of dark red/purple, dark brown and orange. These slag fragments were recovered from locations 25/01/10 (6), 26/01/10 (7), 01/02/10 (4) (5) (8), 02/02/10 (8), 03/02/10 (15), 08/02/10 (9), 09/02/10 (6), 11/02/10 (5), 12/02/10 (1) A3 C19, 13/02/10 (1), 19/02/10 (1), 23/02/10 (5), 26/02/10 (7) and 27/02/10 (4).

All slags of this type are broken and vary in size from the smallest fragment 29mm in length, 28mm in width and 24mm in thickness to the largest fragment 243mm in length, 139mm in width and 78mm in thickness. The thickness of some of the larger fragments can be up to 86mm. Since all fragments have at least one broken edge, a good section of the slags can be seen. All fragments are solid to semi-porous. Most of this porosity is random but in some cases there seems to be greater porosity on the top parts. The gas voids are mostly spherical or globular up to 32mm in size but mainly <15mm. In addition, the fragments from locations 01/02/10 (4) and 12/02/10 (1) have very few flattened or elongated (horizontally) voids up to 40mm in length.

The main characteristic feature of this type of slag are their shaped bases which are curved/rounded perpendicular to the flow of the slag (plano-convex in profile). This suggests that all fragments of this type were channelled away from the furnace in a purposely made ground depression (ditch or channel). Most of these bases are dominated by small rounded undulations like seen on the majority of the slags of other types discussed above but they also have remains of gritty, soily material with many small stone and quartz inclusions (especially on the fragments from locations 25/01/10 (6), 26/01/10 (7), 01/02/10 (4) (5) (8), 09/02/10 (6), 12/02/10 (1) A3 C19, 13/02/10 (1), 19/02/10 (1) and 26/02/10 (7). This makes their bottom surfaces medium to coarse sandpaper rough to the touch and it is sometimes friable in nature. Although the slags themselves are dark grey to greyish blue, this soily material varies in shades of dark reddish orangey brown. This suggests that the slags ran on loose soil which partially fused to the bottom of the slag runs when they were still hot. This is not surprising as if the channels made in the ground to take away the slag from the furnace were indeed intentionally dug, the soil in them was unlikely to have been compacted but left loose. All bases are solid with very few or no voids present but some (from locations 12/02/10 (1) and 27/02/10 (4)) appear to be more agitated with larger rounded projections and undulations probably left by ground surface debris. Most of these impressions appear to be stones and charcoal up to 17mm but mostly <10mm.

The top surfaces of the fragments are all similar. Most fragments seem to have been one flow with no evidence of surface ripples or tendrils. The fragments from 25/01/10 (6), 01/02/10 (5) (8), 12/02/10 (1) and 26/02/10 (7) are dominated by a similar gritty material found on the bottom surfaces. These are coarse sandpaper rough with many small stone or quartz up to 25mm in size but mostly <5mm. Some of the fragments recovered from locations 03/02/10 (15), 12/02/10 (1), 13/02/10 (1), 26/02/10 (7) and 27/02/10 (4) on the other end have rougher and more agitated top surfaces. They have small to medium sized projections of material of which many seem to have broken after deposition leaving sharp fractures which add to their rough texture. Some of these look like they may have had crimpled top surfaces like the type 1.2 tap slag fragments. In any case the stone and quartz inclusions on most surfaces suggest that most of these slags were probably covered in soil when they were still hot. This may have happened to protect the smelters from the heat emanating from the slag runs allowing them to get closer to the furnaces. The top surfaces are for the most part dark greyish blue in colour but like the bottom surfaces the soily gritty material varies in shades of dark reddish orangey brown. Most of these surfaces are solid but many of the rougher agitated surfaces have broken projections revealing surface porosity. Most of these voids are small and globular or spherical.

Since fragments of this type appear to have been channelled they are mostly elongated in plan and in many cases their edges (parallel to the slag flow) are still intact. These edges are well rounded and smooth. The majority of the fragments recovered from locations 01/02/10 (5) (8), 03/02/10 (15), 12/02/10 (1), 26/02/10 (7) and 27/02/10 (4) however, are broken on both ends and must have been part of larger flows of tap slag. A few fragments of interest on the other hand, found in locations 25/01/10 (6), 26/01/10 (7), 01/02/10 (8), 12/02/10 (1) and 27/02/10 (4), appear to have one end intact. These intact ends are well rounded and are either wider or narrower than the main body of the slag. The fact that they are rounded suggests that these fragments are the end of the slag flow.



25/01/10 (6)

26/01/10 (7)

01/02/10 (5)

01/02/10 (8)

03/02/10 (15)

12/02/10 (1) A3

12/02/10 (1) A3

12/02/10 (1) A3

12/02/10 (1) C19


13/02/10 (1)


26/02/10 (7)

27/02/10 (4)

Of special interest are fragments recovered from locations 01/02/10 (4), 09/02/10 (6) and 19/02/10 (1). These are very similar to the type 2 fragment from 08/02/10 (9) discussed above. They appear to represent the start of a slag flow. Both ends are broken but one end is much rougher and agitated, dominated by small to medium sharp protrusions partially due to the larger concentrations of charcoal impressions and the many broken projections. These ends resemble furnace slag and may indeed have been inside or close to the opening of the furnace structure. A few centimetres from that end the slag fragments turn into more common tap slag with smooth rippled flat top surfaces. The fragments from 01/02/10 (4) and 19/02/10 (1) are almost circular or oval in section at the rough end with the smoother tap slag fanning out from there. A good comparative description would be the wrist being the rough end and the open hand the slag fanning out from the furnace. It is likely that the slag was let out through a small rounded opening in the furnace structure which may have caused the rough end to take the shape of that opening. In support to that theory is that there are remains of clay around the rough end on the fragment from 01/02/10 (4).

01/02/10 (4)

09/02/10 (6)

A few fragments from 02/02/10 (8), 08/02/10 (9) and 23/02/10 (5) differ slightly in shape to those discussed above. They are still slag that looks to have been channelled away from the furnaces with medium sandpaper rough rounded bottom surfaces but they are almost cylindrical or conical in shape. The sides are intact but all ends are broken. One end is always wider than the other perhaps suggesting that they solidified in a conical hole in the furnace. Another possibility is that they solidified in a tuyere. Tuyeres may have been used to tap slag out of the furnaces or it may just have been tuyeres used to introduce air flow in the furnace that got plugged with slag. Since no tuyere fragments adhere to the edges of these slag fragments this theory cannot be proved but their general shapes are indeed approximately similar to the internal diameter of some of the tuyeres recovered. Their top surfaces mostly suggest that they were single flows of slag with no surface ripples or tendrils. These vary from smooth to medium rough with the fragment from 08/02/10 (9) having a more agitated top surface with small sharp protrusions of material. Like most slags of this type they are solid to semi-porous with randomly situated globular or spherical voids <8mm in size. Some of these voids are present on the top surfaces where the thin crust covering them has broken after deposition.

02/02/10 (8)


02/02/10 (8)


08/02/10 (9)

23/02/10 (5)

Appendix C.2 - Furnace Slag

Furnace slag is one of the most abundant material types in the assemblage recovered during the Pioneering Metallurgy project 2010. Many sub-types of furnace slag have been identified and the following section will deal with the characterisation and description of each sub-type. Table 1 below shows the quantity in weight (grams), size range (millimetres) as well as colour, charcoal impression size and magnetism of each sub-type of material in each location. All photographs relate to the text directly preceding them.

Table 1 - The quantity in weight (grams), size range (millimetres), colour, charcoal impression size and magnetism of each sub-type of furnace slag in each location.

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
25/01/10 (6)	2.1	26108	lot	Dark grey purple – dark reddish brown + orange patches	<10-211	<10-175	<10-97	P - VP	S G E few	<12 <30	Imp <30	p
	5	1734	3	Dark grey – light grey – brownish orange patches	116-147	104-128	38-23	L - SP	S G	<14	Imp <20	
	5 large	3140	1	Dark grey purple – dom dark brown + dark red/purple patches	278	195	51	SP-P	S G I	<7		p
	5	330	2	Dark grey purple – dom dark brown + dark reddish brown	75 103	51 60	14 37	SP-P	S G I	<8	Imp <15 (few)	p
26/01/10 (7)	3	200	1	Dark grey – mid/ dark brown + orangey patches	58			SP	S G	<5	voids <20	
	5	2437	3	Dark blueish grey – dark brownish red + brownish orange patches	60-162	55-81	31-104	L-SP	S G E	<3 <15		
	1.2	2030	2	Dark grey – dark brownish red + brownish orange patches				SP	S G	<7	Imp <20	
	1.2	10210	1	Dark grey – dark brownish red + brownish orange patches	250		150	L - SP	S G	<7	Imp <20	p
26/01/10 (8)	1	4830	2	Dark greyish blue – dark brownish red/ orange patches	102 168	73 118	93 88	S	S G	M <10 Up to 33		
	3	6430	2	Dark grey – dark brownish orange patches	203 199	145 159	115 118	SP	S G E few	<15	Imp <25 (few)	
	5	1380	1	Dark grey – mid brown patches	181	112	56	SP	S G	<10		
	5	479	2	Dark grey – dark brownish red +	49	35	26	L	S G I	<15	Imp <20	

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
				brownish orange patches								
	2	360	8	Dark grey – dark orangey brown patches	<70			SP - P	S G E	<10 <35		
28/01/10 (1)	5	1900	2	Dark grey – lots of dark brown patches	89 136	73 136	55 64	S - SP	S G	<18	Imp <10	
	5	2064	6	Dark grey – dark brownish red/ orange patches	43-154	30-126	19-38	SP - P	S G E thin	<8 <13	Imp <40	
	2.1	1220	10	Dark grey – dark brownish red/ orange patches	<94			P	S G	<8	Imp <15	
28/01/10 (2)	3	960	8	Dark grey – dark brownish red/ orange patches	<80			SP	S G	<8	Imp <15	
28/01/10 (5)	6	500	2	Dark grey – metallic shiny on breaks	<97			P - VP	S	M <6		
29/01/10 (1)	5	680	1	Dark grey – dom dark brownish red/ orange patches	136	101	54	SP	S G N few	<3 <15		p
	2.1	837	1	Dark grey – dark brownish red/ orange patches	111	99	68	P	S G	<10	Imps + voids <20	
29/01/10 (2)	1	2490	1	Dark grey – dark red patches – base dark red/purple	183	155	84	SP	S G E few	<14 <56	Imp <6 on base	
	2	900	1	Dark grey – dom dark brownish orange patches	157			VP	S G I	<5 <12	Imp <25	
29/01/10 (4)	1	2220	1	Dark grey – dom dark red/ purple + orange patches	202	167	58	SP - P	S G	<11	Imp <42 on upper	p
	6	1130	1	Dark grey – brown patches	165	125	86	VP	S G N	<10	Imp <34	
	6	73	1	Dark grey – dark red patches	62	58	25	SP	S G	<1		
29/01/10 (5)	5.1	1770	4	Dark grey – dark red/ purple patches	62-108	45-80	37-66	S	S G E few	<12 <36	Imp <37	
	3	784	5	Dark grey – dark brownish orangey red patches	52-82	48-63	20-34	L	S G	<10	Imp <7	
30/01/10 (1)	5	770	2	Dark grey/ black – light grey + brown orange patches	79 113	55 95	26 38	S - SP	S G	<8		p
	5	2290	1	Dark grey – dark brownish red patches	242	153	75	SP-P	S G I	<18	Imp	
	? S	130	1	Dark grey – light grey + orange patches	71			S	S G	<8		
	1	1700	1	Dark grey – some crystallisation – mid grey + brown patches	173	141	83	S-SP	S G E	<10 <91	Imp <29 – tiny imps base	
	?	210	2	Dark grey purple – dom white + brown + orange patches	<75			P	S G I	<6	Imp <18	
30/01/10 (2)	1	9340	2	Dom dark red/purple	290 302	170 230	105 93	SP	S G I	<30	Imp <40 - on base <5	

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
				patches – yellowy orange patches								
	1.2	3880	1	Dark grey – dom light to dark brownish grey – orangey yellow patches	200		105	L	S G	<5	Imp <10 – Imp on base <6	
01/02/10 (1)	2	2450	5	Dark grey/ black – dom brown orange patches	61-196	58-125	31-73	VP	S G	M <4	Imp <50	
	3	970	3	Dark grey – dom brownish orange patches	86-116			SP	S G	M <12	Imp <20	
	5.1	2020	1	Dark grey – dom brown + orange patches	203	152	106	SP	S G	<14	Imp <32 few	
01/02/10 (2)	5.2	1280	3	Dark grey – brownish orange patches	80-124	57-85	31-67	S-SP	S G I	M <13 <14		
	3	1230	2	Dark grey – dom dark red/ purple patches	138 134	89 92	53 64	SP	S G	M <8	Imp <30	p
	5.1	2020	1	Dark grey – dark brown patches – shiny crystallisation	104			S	S G	M <6	Imp <15 few	
01/02/10 (3)	5.1	430	1	Dark grey – dark brownish red patches + orange lump	103	77	30 up to 59	SP	S G	<5		l
01/02/10 (4)	4	350	3	Black – dark red patches	<89			VP	S G E	<4	Imp <15	
	1.2	3150	1	Dark grey – dark brownish red + light brownish grey patches	208	150	104	S-L	S G E ver	<10 <20	Imp <20 – on base <5	
01/02/10 (5)	1.2	5250	1	Dark grey – dom dark brownish red + orange patches	205	182	114	SP P	S G	<18	Imp <58	p
	1.2	5060 dip	1	Dark grey – dark brownish red + brownish grey patches	223	205	150	S-L	S G E	<3 <22	Imp <15 few – on base < 40 lots	p
	5.1	370	2	Dark grey – some metallic shiny crystallisation	<86			P	S G	<12	Imp	
	4	240	1	Dark grey – dark red + orange patches	107			P	S G	<3	Imp <25	
01/02/10 (6)	5.1	2260	3	Dark grey – brown + dark red patches	100-152	73-111	62-58	SP	S G E	<7 <74		
	5	640	3	Dark grey – brown + dark red patches	133 90	50 55	37 35	S-SP	S G	<8		
	1.3	2423	1	Dark grey/purple – dom dark brown – dark brownish red + yellowy orange patches	211	177	55	S-L	S G	<1		
01/02/10 (8)	5	1650	3	Dark grey – dark brownish red patches	65-148	56-122	48-45	SP	S G	<10	Imp <35	
	6	4390	lot	Dark grey – dark brownish red/ orange patches	<10-105	M 45-90		P-VP	S G	<5	Imp <15 few	p
02/02/10 (1)	1.3	23140	7	Dark grey – dom dark brown + dark	165-287	144-255	54-80	S-SP	S G N	<12 <37	Imp <40 few – m<12	p

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
				red + light grey patches								
	2	480	1	Dark grey – dark brown + orange patches	138			VP	S G	<5	Voids <33	
	?	1520	1	Dark brownish red	139	114	74	S	S G	<10		
02/02/10 (4)	2	380	3	Dark grey – dom dark brownish red /orange patches	34-94			P	S G	<4	Voids <44	p
02/02/10 (5)	1.2	12690	3	Dark grey – dom dark brownish orangey + red + greyish white patches	202-221	126-171	117-132	S-SP	S G	<15	Imp <43 – on base imp + void <20	p
02/02/10 (6)	2	710	1	Dark grey – dark reddish brown patches	109			SP-P	S G	<9	Imp <39	p
	3	550	1	Dark grey – dark brownish orange patches	123			SP	S G	<7 <10	Imp <18	
02/02/10 (7)	2.1	1860	1	Dark grey – dom dark brown, black reddish purple orangey patches	154	135	103	VP	S G I	<6	Voids <45	
02/02/10 (8)	1.5	8100	6	Dark grey – dark brownish red/ purple + orange patches	115-143	100-113	75-63	S-SP	S G	<6	Organic imp <30 (2-3 wide)	
	1.5	970	3	Dark grey – dark brownish red/ purple + orange patches	<93				S G	<6		
	5.2	280	3	Dark grey – dark brown + orange patches	75-73	25-37	15-37	SP	S G	<6		
03/02/10 (1)	1	1160	1	Dark grey – dom mid grey + dark red/orange patches	134	102	64	S	I	<10		
	3	640	4	Dark grey – dom mid grey + dark red/orange patches	69-98			SP	S G	<8	Imp <15	
03/02/10 (3)	2.1	570	1	Dark grey – dark brownish red patches	108	94	75	P	S G	<7	Voids <15	p
	2	1220	1	Dark grey – dark brownish orange patches	140	105	92	P	S G I	<6	Imp <25	P
	5	2040	1	Dark grey – dark brownish red and orange patches	222	115	59	SP	S G	<7	Imp <15	P
03/02/10 (4)	1.1	3850	2	Dark grey – dark red + orange patches – shiny crystallisation - Base dark reddish orangey purple	176-208	170-138	50-74	P	S G I	<13	Imp <35 – on base <5 lots	p
	5	1250	2	Dark grey – dark red + orange patches – shiny crystallisation	104-148	96-86	55-39	S - SP	S G	<8		
03/02/10 (6)	1	960	1	Dark grey – dark red purple patches	?			SP-P	S G N	<10 <23	Imp <25	

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
	5	560	1	Dark grey – dark brownish red patches	131	83	40	SP-P	S G I	<12		
	2.1	725	2	Dark grey – dark red + purple + brown patches	106 118	85 82	37 51	P-VP	S G	M <12	Imp + voids <15	
03/02/10 (9)	2.1	1020	1	Dark grey – dark brownish red patches	157	123	83	P-VP	S G I	<12 <10	Voids <30	
	2.1	512	1	Dark grey – dark purplish red + orange patches	100	65	54	L	S G	<1	Imp <15	p
	5.1	1090	2	Dark grey – dark brownish red patches	118-195	79-83	53-56	P	S G	<7	Imp <60	
03/02/10 (11)	5	3450	2	Dark grey/ shiny purple – dom dark brown	144 169	145 134	75 100	S P	S G I	<10		
	5.1	390	2	Dark shiny grey – dom dark brown + orange patches	71 90	47 80	29 44	SP	S G I	<6		p
03/02/10 (12)	5	1288	3	Dark grey – dark purple + orange patches	49-115	40-92	35-60	SP	S G I	<7		
03/02/10 (13)	5	890	3	Dark grey purple – dark red + orange patches	80-134	60-103	23-44	P-VP	S G	<15	Imp <7 base	
	3	633	1	Dark grey – dom brownish yellowy orange – dark brownish red patches	83	85	66	S-L	S G	<5		p
03/02/10 (14)	1.2	7520	2	Dark grey – dom orangey yellow + dark red/ purple patches	188 195	163 192	82 113	S P	S G I	<16 M <5	Imp <45	p
	1	2870	1	Dark grey – dark red + brownish yellowy orange patches	290	209	68	L	S G	<15	Imp <20	p
	?S	757	2	Dark grey shiny - crystallisation	<79			S-SP	S G	<8		
03/02/10 (15)	1.2	4910	2	Dark grey – dark red patches	213 115	192 97	97 58	SP-P	S G I	<10	Imp <50	p
	2	230	2	Dark grey – some orangey brown	<72			P	S G	<8	Voids <20	
	4	119	1	Dark grey – dom dark purplish red – yellowy orange patches	58	62	39	SP	S G I	<8		p
05/02/10 (1)	2	1150	1	Dark grey – dom dark purplish red	164	92	120	P	S G	<4	Imp + voids <25	
05/02/10 (2)	5.1	2060	2	Dark grey – shiny crystallisation – dom dark reddish brown	126-123	98-109	58-81	L-P	S G E few	<11 <33	Imp <20 top – imp <6 base	p
	2	429	1	Dark greyish blue – dom dark brownish red	107	87	68	P	S G	<5	Imp + voids + inc <40 – M <20	p
05/02/10 (3)	5	4570	1	Dark brown - dom mid grey + dark brownish orange patches	252	195	72	S-SP	S G	<14	Imp <25	
	1	949	1	Dark grey – dark purplish red yellowy orange patches – crystallised	173	120	30	S-L	S G I	<3	Imp – on base imp <10 M<5	

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
	1	650	1	Dark grey – dark brownish red patches	205	83	37	SP	S G	<8	Imp <15 (>400 inner diameter)	
05/02/10 (4)	1	2640	3	Dark grey – dom brown + dark reddish brown patches	121-209	102-181	21-68	SP-P	S G I	<16	Imp <35 top – imp <5 base	
	5	726	2	Dark grey – dom brownish grey - yellowy orange patches	69 128	56 81	30 48	L-SP	S G I E	<12 <4	Imp <5	
05/02/10 (6)	1.2	4650	4	Dark grey – dark red/purple patches + orangey brown patches	87-184	58-117	47-65	SP-P	S G I E N few	<15 <50	Imp <30 top – imp <12 base	p
	2	270	8	Dark grey – dark red + brown patches	<55			P	S G I	<7	Voids <15	
	5	1039	2	Dark grey – dark brownish red + yellowy orange patches	92 116	76 97	44 52	P	S G	<12	Imp + inc < 12 – base <5	p
05/02/10 (7)	5	4930	1	Dark grey + purplish – dom brown + dark red patches	316	330	103 M <55	SP	S G I	<7	Imp <23	p
06/02/10 (2)	1.1	1010	1	Dark grey – shiny crystallisation – dark brownish red + orange patches	145	132	33	P	S G I	<6	Imp <6 base	p
	2.1	1140	1	Dark grey – dark red patches	184	115	64	SP-P	S G	<10	Imp <20 top – imp <12 base	
	3	760	1	Dark grey – dom dark brownish orange + red patches	121	100	55	S	S G	<6	Imp <12 base	p
	5.2	110	1	Dark grey – dom dark brownish orange + red patches	83	39	28	SP	S G	<5		
	4	516	2	Dark grey – dark brownish red + yellowy orange patches	56 111	56 95	59 43	SP-P	S G	<2	Imp + inc <20 – M <10	p
06/02/10 (3)	1/1.1	11814	3	Dark grey – brownish orange patches + base brownish red	150-313	302	100	L-P	S G I	<30 M<15	On base imp <5	p
06/02/10 (4)	2	23	1	Dark grey – dark brownish orange patches	<50			P	S G I	<2	Voids <16	
08/02/10 (1)	1	7750	3	Dark grey – dark red + brown patches – orange base	182-280	125-253	42-82	SP	S G I	<11	Imp <40 top – imp <7 base	p
	1	842	1	Dark grey – dark brownish red + yellowy orange patches	105	97	56	SP-P	S G E N	<7 <20		
	5.1	540	1	Dark grey – dom dark orangey brown	111	111	53	S-SP	S G	<5	Imp <15 top – imp <20 base	
	2.1	490	lot	Dark grey – dark red + orangey brown patches	<82			P-VP	S G I	<10	Voids <17	p
	1.1 crust	870	1	Dark grey – dom mid grey – dark	206	159	16	S-SP	S G I	<6		p

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
				red + black patches – orangey red brown base								
	5	1050	2	Dark grey – dark red + orangey brown patches	80 198	53 100	33 52	S - SP	S G I	<10	Imp <14	p
	1.4 small	1670	1	Dark grey – dark brown + orangey brown patches	158	142	55	S- SP	S G	<12		l
08/02/10 (2)	1.2	4120	1	Dark grey – dom dark brownish red patches	214	161	131	S- SP	S G	<10	Imp <25	
	1	1958	2	Dark grey – dom mid grey + reddish brown	125 179	93 146	50 49	SP	S G E few	<6 <12	Imp <10	
	5.1	700	2	Dark grey – dark red patches + dark orangey brown	77- 131	64- 111	35- 38	S P	S G I	<10	Imp <17	p
	6	190	1	Dark grey – dark red patches – orangey red base	104	65	29	P- VP	S G I	<8		
	2.1	150	2	Dark grey – dark red patches	<62			SP	S G	<12	Imp + void <20	
08/02/10 (3)	5	4090	4	Dark grey purple – dark red patches – dom dark brown	147- 186	120- 146	35- 63	SP	S G I	<13	Imp <27 top – imp <5 base	p
	2.1	384	3	Dark grey – dark reddish brown patches	90 114	49	43	VP	S G	<7	Imp + vids <27	
08/02/10 (4)	1	7690	5	Dark grey – dark orangey brown patches + few red	135- 227	50- 180	38- 84	S- SP	S G E few	<11 <40	Imp <32	p
	2.1	210	lot	Dark grey – dark brown + red patches	<59			P- VP	S G I	<10	Imp <13	
08/02/10 (5)	1.3?	3650	1	Dark grey – dom mid/dark grey + dark brownish red	271	185	99	SP	S G	<5	Imp + void <30 – m <12	p
08/02/10 (6)	1	1060	1	Dark grey – dark brownish red patches	171	83	74	SP	S G E ver	<10 <30	Base <6	
08/02/10 (9)	5	3327	6	Dark grey – dark reddish/purplish brown patches	<120 175	114	72	L- SP	S G I	<9	Imp <38	p
	1.1	3130	2	Dark grey – brownish red orange patches + orangey red base	150 205	150 152	72 57	P- VP	S G E	<10 <50	Imp <30 top – Imp <10 base	m
	3	1400	1	Dark grey – dark reddish brown + dark brown patches	151	110	88	SP- P	S G	<10	Imps/voids <33 – m <15	m
	2.1	780	2	Dark grey – dark brown + purplish red patches	68 144	67 88	32 58	P	S G	<8	Imp <17	p
	1.4	1350	1	Dark grey – dom dark reddish brown	182	167	59	VP	S G I	<5	Imp <20 – on base imp <10 lot	
	5.2	466	1	Dark grey – dom dark reddish brown	116	42	51	SP	S G	<10	Imp <10	
08/02/10 (10)	5.1	3010	2	Dark grey – shiny crystallisation – dark red + orange patches	121	73	42	S- SP	S G E ver	<12 <32	Imp <6 base	p

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
	5	2830	3	Dark grey purple – dark red patches – dom dark brown	142-139	99-131	60-58	SP-P	S G I	<7	Imp <16	p
	1.2	1670	1	Dark grey – dom dark brown + orange patches – some purple	165	144	78	SP-P	S G I	<10	Imp <18 top – imp <12 base	p
	5.2	1430	1	Dark grey – dark reddish brown patches	198	153	91-40	S-L	S G	<5	Imp + voids <22 on thick end	
	2	388	2	Dark grey – dom dark reddish brown + yellowy orange patches	<60			P-VP	S G	<2	Voids <20	
09/02/10 (1)	2.1	1272	2	Dark grey – dom light to mid grey	123 153	105 134	75 67	VP	S G	<5	Voids + inc <40 lot	
09/02/10 (2)	5	1420	1	Dark grey – dark red patches	172	124	60	L-SP	S G E	<5 <7		
	?S	1540	1	Dark grey purple – dark red + orange patches	133			S	S G	<7		
	1.2	1370	1	Dark grey – dom dark brown + reddish orangey brown patches	147	125	96	P	S G I	<6	Imp <19 top – imp <6 base	p
09/02/10 (4)	?S	261	4	Dark grey/blue	<70			S-SP	S G	<4		
09/02/10 (6)	1 large	5740	3	Dark grey – dark brownish red + orange patches	60-200	58-173	52-117	S-SP	S G E	<10 <45	Imp <6 base	p
	6	1560	1	Dark grey crystallised – dark red base – orange patches	210	123	151	VP	S G I E	<15 <120	Imp <10 base	
	1	4900	5	Dark grey – dark red + orangey brown patches	103-203	99-123	50-68	S-SP	S G	<12	Imp <15 top – imp <12 base	p
	2	890	2	Dark grey – dom dark brown and orangey patches	<120			P-VP	S G I	<10	Imp <30	
	5	560	2	Dark grey – dom dark brown and orangey patches				S-SP	S G	<16	Imp <15	
09/02/10 (7)	1	5269	3	Dark grey – dark brown + red + orange patches – crystallised shiny green fracture	169-280	84-264	53-92	VP	S G I	<15	Imp <40 top – imp <7 base	p
	4	40	1	Dark purplish grey – dark red – pale green				VP	S G I	<8	Voids <17	
	5.2	70	1	Dark grey – dark reddish brown	87	35	25	SP	S G	<3		
10/02/10 (1)	1.2	4010	3	Dark grey – dom dark brown – dark red + orange patches	73-177	66-120	72-89	SP	S G	<5	Imp <40	p
	2.1	707	2	Dark grey – dark brownish red + orange patches	<93			SP-P	S G I	<14	Imp + voids <35	p
10/02/10 (2)	2	100	1	Dark grey – dom dark brown + dark red orange patches	85			VP	S G I	<8	Voids <28	
11/02/10 (1)	1	3120	1	Dark grey – dark red patches	217	134	100	S-SP	S G I	<12	Imp <15 top – imp <25 base	p

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
	1.2	2920	1	Dark grey – dark red patches + orange + purple patches	200	180	94	SP-P	S G I	<11	Imp <22 top – imp <17 base	p
	2	234	1	Dark grey – dom dark grey + dark brown patches	85	70	48	SP-P	S G	<3	Voids <75 lots	
11/02/10 (5)	2	50	1	Dark grey – dark red + orange patches	<46			P	S G I	<3	Voids <22	
11/02/10 (6)	5	901	2	Dark grey – dark brown + orangey reddish brown inner	79 169	 96	21 52	SP	S G I	<11	Imp <11	
	1.2	4130	1	Dark grey – dark reddish/purplish brown patches	208	151	102	S-L	S G	<4	Imp <15	
12/02/10 (1)	1.1	5330	3	Dark grey – dark red + brown patches – orangey base	173-245	134-218	62-71	P-VP	S G I	<12	Imp <40 top – imp <6 base	
	2	558	2	Dark grey – dom orangey brown + reddish brown	74 104	51 78	38 50	P	S G	<3	Voids <25 lots	
	?	120	lot	Dark grey – dark red + brown patches – orangey base	<41			P-VP	S G I	<5		
	3	682	1	Dark grey – dom orangey brown + dark brownish red patches	116	73	62	S-L	S G	<4		p
A3	1.2	1930	1	Dark grey – dom whitish grey + dark red/purple brown patches	136	107	128	S-SP	S G	<6	Imp + voids + inc <20	p
	5/4	451	6		<80							
A8	5.1	5405	lot	Dark grey – dom whitish grey + brownish orange + dark brownish red patches	<150			SP-P	S G E few	<5 <50	Imp <30	p
	1.2	2621	3		130 144	107 134	70 70	SP-P				p
	4	1240	lot		<50							
C19	5.1	960	4	Dark grey – dom whitish grey + dark red/purple brown patches	<150			SP	S G I E few	<10 <30		
	5	1344	5		<80							
12/02/10 (2)	6	335	few	Dark grey – dark brownish red patches	<74			VP	S G E few	<4 <35		
12/02/10 (3)	1.2	5550	1	Dark grey – dom mid grey + orangey brown patches	240	203	117	P	S G	<14	Imp <50 top – imp <40 base	p
	3	1096	3	dark grey/purple – dom dark brown red + orange patches	91 103	78 67	51 63	S-L	S G E few	<18 <19	Imp <12	
12/02/10 (5)	3	350	1	Dark grey – dom dark brownish red + orange	96	70	45	S-SP	S G I	<6	Imp <10	p
	5	849	1	Dark grey – yellowy brownish orange patches	163	78	51	SP	S G	<4		p
12/02/10 (6)	3	780	2	Dark grey – purplish fracture – dark brownish	85 92	70 77	38 94	SP-P	S G	<9	Imp <13	p

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
				red + orange + mid grey patches								
	5	504	2	Dark grey – dom dark reddish brown + brownish red	71 108	53 105	26 39	SP	S G I	<6 <12		
	4	120	3	Dark grey – mid grey + dark red + orange patches	<67			SP-P	S G I	<8		
12/02/10 (7)	5	1600	1	Dark grey – dark brown + dark red patches	149	135	70	SP	S G I	<10	Imp <15 base	p
	3	560	3	Dark grey purple – dom mid brown + dark red patches	<105			SP-P	S G I	<7	Imp <20	
12/02/10 (8)	4	120	1	Dark grey – dark red + brown patches	77	53	40	P	S G	<10	Imp <20	p
	3	430	1	Dark grey – dark red + brown patches	90	65	63	S	S G	<7	Imp <15	p
	5	428	1	Dark grey – dom dark brownish orange/red – base greyish white	106	95	37	SP	S G E few	<2 <16		
12/02/10 (10)	3	371	4	Dark grey – dark brownish orange patches	<78			SP	S G I	<4	Imp <12	p
13/02/10 (1)	?S	320	1	Dark grey – dark red + brown patches	98	48	57	SP	S G	<9	Imp <20	
	5.2	545	1	Dark grey – dom dark orangey brown	132	65	47	SP	S G E few	<16 <45	Imp <10	
13/02/10 (2)	1.1	1520	1	Dark grey – dark brown + dark red patches	151	118	80	P-VP	S G	<9	Imp <20	
	1.1	2470	1	Dark grey – dark brown + dark red patches	225	139	115	P	S G	<12	Imp <35 top – imp <6 base	
13/02/10 (3)	1.1	2340	2	Dark grey – dark brown + red/ orange patches – orange base	164 209	98 130	55 68	VP	S G	<11	Imp <29 top – imp <6 base	p
	1	1130	1	Dark grey – dark brown + red/ orange patches	128	95	76	S-SP	S G	<7	Imp <20	
13/02/10 (8)	6	430	3	Dark shiny grey – dom dark orangey brown + dark red patches	50-95			P-VP	S G I	<4	Imp <18	p
13/02/10 (8)	3	70	1	Dark grey – dark red patches	50			S-SP	S G	<6	Imp <10	
13/02/10 (13)	1.4	534	1	Dark grey – dark brown + reddish brown patches	110	81	52	SP	S G	<12 m<6		
13/02/10 (15)	1	6140	2	Dark grey – dom dark orangey brown	200 370	134 275	59 70	SP	S G E	<5 <25	Imp base <7 lots	
15/02/10 (2)	1	1290	1	Dark grey – dark brown + red patches	130	80	85	SP	S G	M<12 Up to 30	Imp <6 base	
	6	490	1	Dark grey – dark red patches	178	117	37	VP	S G	<10	Imp <50	
15/02/10 (3)	6	500	3	Dark grey black – dark brownish red + orange patches	<111			VP	S G I	M<6	Imp <8	

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
	4	32	3	Dark grey – dark red patches	30-45	33	23	SP	S G	<1	Imp <10	p
16/02/10 (1)	5.1	229	1	Dark grey – dark brownish red patches	79	55	35	SP	S G	<7	Imp +void + inc <14	p
16/02/10 (2)	5	410	2	Dark grey – dark brown + red patches	91 73	44 69	37 50	SP-P	S G	<9	Imp <16	p
	1	490	1	Dark grey – dom dark brownish red/purple – orangey brown base	117	111	46	SP	S G I E ver	<8 <15	Imp <35	p
	2.1	527	2	Dark grey – dark orangey reddish brown	95 121	72 82	25 57	P	S G	<18 m<10	Imp + voids <35	p
16/02/10 (4)	1.1	810	2	Dark grey – dom dark brownish red/purple – orangey brown base	124 137	85 105	38 41	P-VP	S G I	<22	Imp <30	p
16/02/10 (5)	5	1663	4	Dark grey – dark brown + red/ purple + orange patches	76-150	58-108	29-37	P	S G I	M<15	Imp <25	
16/02/10 (6)	1.1 large	9456	2	Dark grey – dark red/purple + orange patches – orangey brown base	119 323	63 292	74 130	P-VP	S G I E N	<12 <35	Imp <35 top – imp <17 base	
	5	820	2	Dark grey – dom dark red + orange patches	100	66	40	S-SP	S G	<8		p
	2	440	2	Dark grey – dom dark reddish brown + orange patches	<103			VP	S G	<7	Voids <20	
	2.1	260	2	Dark grey – dom light grey – dark brown + orange patches	<72			P	S G	<6	Voids <20	
17/02/10 (1)	3	2722	14	Dark grey – dark red/purple + dark brown/orange patches	63-73	53-48	38-51	S-P	S G	<15	Imp <20	p
	1	960	1	Dark purplish grey – dark yellowy orange + dark red patches	101	93	64	L	S G I	<2		
17/02/10 (2)	5.1	840	2	Dark grey – dark red + brown patches – one with orangey brown base	85 92	69 78	37 63	S-SP	S G I	<9		p
	6	125	1	Dark grey – dom dark brownish red	94	49	44	VP	S G I	<3		
17/02/10 (3)	4	500	3	Dark grey – dark orangey brown + red patches	<91			P-VP	S G	<10		p
17/02/10 (4)	3	50	2	Dark grey – dark orangey brown patches	<40			S	S G	<4		
	2	192	1	Dark grey – dom dark reddish orangey brown	94	58	34	SP-P	S G	<9	Imp + voids <17	
17/02/10 (5)	5.1	217	2		<70			SP	S G	<6	Imp <10	

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
17/02/10 (6)	3	1486	lot	Dark grey – dark brownish red patches								
18/02/10 (1)	1	730	1	Dark grey – dark orangey brown	122	92	75	SP	S G E	<13 <48	Imp <15	p
	6	798	2	Dark grey – dark red/ orangey brown patches	102 131	77 93	51 53	VP	S G I	<19 m<2	Imp <6	p
	2.1	720	4	Dark grey – dark brown/ red/ orange patches	<116			VP	S G	<7	Imp <30	p
	3	440	4	Dark grey – dark orangey brown + red patches	<76			SP	S G	<7		
18/02/10 (2)	2.1	830	2	Dark grey – dark brown/ red patches	83 92	74	68	SP-P	S G	<6	Imp <18	p
	2	254	1	Dark grey – dom dark brown + reddish brown patches	97	74	43	P	S G	<8	Imp + void <16	p
	5	607	1	Dark grey – dom mid/dark brown – brownish orange redpurple patches	143	97	35	SP-P	S G	<14 m<3	Imp <14 – on base <6	p
18/02/10 (3)	5	470	1	Dark grey/purple – dark brown + orange patches	105	108	43	SP	S G I	<6	Imp <13	p
	2	300	2	Dark grey – dom dark brownish red	70 62	49 58	38 48	SP-P	S G	<4	Imp <17	
18/02/10 (4)	1	2330	4	Dark grey – dark red + brownish orange patches	90- 208	123	62	P	S G I	<10	Imp <30 – Imp <7 base	p
	2.1	1010	2	Dark grey – dark red + orangey brown patches	45 117	100 70	65 36	P-VP	S G I	<12	Imp <25 top – imp <15 base	p
	5	520	1	Dark grey – dark red patches	159	101	35	SP-P	S G I	<9	Imp <18	
18/02/10 (5)	2.1	390	2	Dark grey/purple – dom dark reddish brown patches	57 104	90	53	P	S G I	<7	Imp <16	p
	6	249	1	Dark greyish blue - crystallisation	91	84	40	P-VP	S G I	<5		
18/02/10 (6)	1	2470	2	Dark grey – dark red + orange patches – orangey brown base	141 177	110 125	56 68	S-P	S G I E ver	<10 <30	Imp <34	
	5	2670+?	2	Dark grey – dark red + brown + orangey brown patches	261 254	139 192	53 63	S-SP	S G I	<11 m<2	Imp <20	p
19/02/10 (1)	1	3590	1	Dark grey shiny – dom yellowy orangey brown – base orangey yellow	267	151	72	L-SP	S G	<13 m<5	Imp <15 – on base <5 lot	p
19/02/10 (2)	?	730	lot	Dark grey – dark yellowy brown – dom dark reddish brown	<72			SP-VP	S G	<22		
19/02/10 (3)	5	4640	6	Dark grey/ purple – dom dark brown red orange patches	75- 199	57- 115	37- 52	S-SP	S G I	<12	Imp <40 top – imp <10 base	p
	2.1	2330	2	Dark grey - dom dark brown + red + orange patches	78- 185	140	111	P	S G	<12	Imp <20 top – imp/	

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
											voids <9 base	
	3	870	4	Dark grey – dark orangey brown + dark red patches	58 81	52 71	27 35	S	S G	<13	Imp <6	
	2	880	4	Dark grey black – dark red purple patches	<109			P- VP	S G	<10	Voids <23	p
19/02/10 (4)	2.1	2770	2	Dark grey – dark red patches	129 198	103 118	83 82	P- VP	S G	M <13	Imp <20 top – imp <12 base	p
	1.2	3090	1	Dark grey – dark brown + red patches	251	170	103	SP- P	S G	<10	Imp <20 top – imp <10 base	p
19/02/10 (5)	1.4 small	1340	2	Dark grey – dom dark brown _ red patches – dark brownish red base	139 159	95 109	45 46	S- SP	S G I	<7	Imp <6 base	p
	3	620	2	Dark grey – dark red patches	<100			SP	S G	<8	Imp <15	p
	?S	390	1	Dark grey – dark brown + purple patches	68	50	88	S	S G E few	<9 <40		p
	2.1	973	2	Dark grey – dark brownish red – light grey + dark reddish brown	104 125	83 77	57 81	P	S G	<30 m<12	Voids <25	p
	5	483	2	Dark grey – dark orangey brown + dark brownish red - crystallisation	95 92	35 77	33 21	L- SP	S G I	<12 m<5	Imp <10	
19/02/10 (6)	5	420	3	Dark grey – dark brownish red patches	<105			P- VP	S G	<9	Imp <22	
21/02/10 (1)	3	1270	10	Dark grey – dark red + dark brown + orangey brown patches	40- 82	71	41	S- SP	S G	<7	Imp <15	p
	6	850	6	Dark grey black – dark brown + red patches	<77			P- VP	S G I	<12	Imp <10	
21/02/10 (2)	3	120	6	Dark grey – dark brown + red patches	<50			S- SP	S G	<4		p
21/02/10 (3)	2	430	5	Dark grey black – dark red patches	<93			P- VP	S G	<7	Imp <25	
21/02/10 (5)	?S	300	4	Dark grey – dark yellowy brown + dark red patches	<83			S- SP	S G	<10		p
	? crust	80	1	Dark grey – dom dark reddish brown + orange patches	63	50	15	S	S G	<3		
21/02/10 (6)	6	690	1	Dark grey black – light grey + dark red patches	123			P	S G	<5	Imp <10	
21/02/10 (7)	?	310	3	Dark grey – light grey + dark red patches	<81			P- VP	S G	<7	Imp <15	
21/02/10 (9)	2.1	2860	8	Dark grey – dark red + orangey brown patches	38- 206	128	96	P- VP	S G	<8	Imp <25	
	5.1	1100	3	Dark grey – dark red + light grey – dark brown patches	94 151	61 102	35 66	P	S G I	<13	Imp <15	p

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
22/02/10 (1)	2	600	3	Dark grey – dark red patches	33-90			SP-P	S G	<4	Voids <15	p
22/02/10 (3)	3	480	3	Dark grey – dark brown + light grey patches	57-73	42-56	26-39	S-SP	S G	<11		
	1.1	740	1	Dark grey – dark purple + mid grey patches – some dark brown	134	154	43	VP	S G I	<9		
	5.1	760	1	Dark grey – dom yellowy brown	142	104	51	SP	S G	<6		p
	2.1	2200	13	Dark grey – dom dark red + orange + brown patches	26-166	98	113	VP	S G I	<15	Imp + voids <45 m<20	p
22/02/10 (4)	5	1010	1	Dark grey purple – dom mid grey + orangey brown	131	119	58	SP	S G I	<8		p
	2.1	430	2	Dark grey – dom dark brown + dark red patches	<93			SP-P	S G	<8		
23/02/10 (1)	5.2	130	1	Dark grey – dark red patches	90	29	29	SP	S G	<13		
	1.1	2490	1	Dark grey – dark red patches – dark brownish red base	249	145	83	VP	S G E	<15 <80	Imp <30	p
	6	81	1	Dark greyish blue metallic – dom mid/dark brown	55	43	25	L	S G	<4 m<1		
23/02/10 (2)	1.1	390	1	Dark grey shiny – dark red patches – dark red base	83	67	52	P-VP	S G	<3		p
	6	200	2	Dark grey – some light grey + orange patches	<93			VP	S G I	<7		
	2.1	240	3	Dark grey – dark brown + light grey patches	<62			SP	S G	<5		p
23/02/10 (3)	1	12020	1	Dark grey – base orangey brown + reddish brown patches	334	320	96	L-SP	S G N	<10 <15	Base imp <6	p
23/02/10 (4)	5	380	1	Dark grey – dom dark brownish red	142	70	39	SP	S G I	<6	Imp <10	
	1	1440	1	Dark grey – dark purplish red + reddish brown patches	256	160	65	P	S G E	<5 <40	Base imp <5	
23/02/10 (5)	1.1	480	1	Dark grey – dark red patches – dark brownish red base	142	85	49	P	S G I	<12	Imp <25	p
	6	110	1	Dark grey – dark red patches – dark brownish red base	66	48	36	VP	S G	<5		
23/02/10 (6)	5	470	1	Dark grey – dark brownish red patches	128	84	46	P	S G I	<6	Imp <15	p
23/02/10 (7)	5	1270	2	Dark grey purple – dom dark greyish brown	135 132	76 80	58 57	SP-P	S G I	<15	Imp <17	p
23/02/10 (8)	6	180	1	Dark grey – dark red patches	99	62	40	VP	S G I	<11		
	3	340	1	Dark grey – dom dark brown + red patches	71	75	42	SP	S G I	<8		to p

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
23/02/10 (10)	5.1	440	1	Dark grey – dark brown + red patches	102	88	70	P	S G	<14		
23/02/10 (12)	5.1	1160	2	Dark grey shiny – dark brownish red	84 148	46 116	45 59	P	S G	<15		p
24/02/10 (1)	1?	760	1	Dark grey – dom dark purplish brownish red	138	85	64	S-SP	S G I	<8	Imp <18	
24/02/10 (2)	3	1170	6	Dark grey – dom dark brown + red patches	54- 94	76	49	SP	S G I	<10	Imp <13	
24/02/10 (3)	5	2910	2	Dark grey – dark brown + orange patches	162 198	142 139	43 81	S-SP	S G I	<8		p
	6 crust	100	1	Dark grey – purple + dark red patches – dark orangey brown base	85	57	18	SP	S G	<3		
	2.1	1200	1	Dark grey – dark red patches	146	102	91	SP	S G	<7	Imp + voids <15	
	5.1	430	2	Dark grey – orangey patches	<89			SP	S G	<5	Imp <10	p
24/02/10 (4)	5	700	2	Dark grey – dark orangey brown patches	98 155	48 55	31 55	SP-P	S G N	<8 <15		
	5	3920	1	Dark grey – dom mid/dark brown + dark orangey reddish brown	260	267	55	SP	S G N	<4 <26	Base imp <6	
25/02/10 (1)	1.3	3330	1	Dark grey purple – dark brownish orange + dark red + black patches	235	216	58	SP	S G I	<9	Imp <10 base	p
	6	3260	1	Dark grey purple – dark brown + orangey brown patches	157	145	125	SP	S G I	<10	Imp <25	p
	3	190	4	Dark grey – dark brown + orangey brown patches	<63			SP	S G	<6	Imp <20	p
25/02/10 (4)	2	80	1	Dark grey – dark red patches – pale green base	64	50	23	SP	S G	<5	Voids <18	
25/02/10 (5)	3	280	5	Dark grey – dark brown + orange patches	<64			S-SP	S G	<8	Imp <15	p
25/02/10 (8)	5.1	150	1	Dark grey – dark brown + red + orangey brown patches	57	51	41	SP	S G	<3	Imp <13	
26/02/10 (1)	1	5250	1	Dark grey – dark brown + red + brownish orange patches	361	272	96	S-SP	S G I	<9	Imp <35 top – imp <8 base	p
	2	1230	3	Dark grey – dom dark brownish red + orange patches	79 140	88	77	SP-VP	S G	<5	Imp + voids <36	p
	2.1	1310	3	Dark grey – dom mid grey – dark red + purple patches	<176			SP-P	S G	<9	Imp <19	
	3	200	6	Dark grey – dark brown + red patches	<48			S-SP	S G	<7		p
26/02/10 (3)	1	870	2	Dark grey – dark brownish red + purple patches	108 125	98 110	33 43	S-SP	S G	<7		p

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
	2.1	520	3	Dark grey – dom dark orangey brown + dark red patches	<96			P-VP	S G I	<7	Voids <18	
	4	414	2	Dark grey – dark orangey brown + brownish purplish red	88 106	 57	 36	P	S G	<10 m<5	Imp <25 m<15	p
	5.2	61	1	Dark grey – orangey brown + dark reddish brown	72	14	20	L	S G	<2		p
26/02/10 (5)	1.2 small	2770	1	Dark grey – dark reddish brown base	207	167	74	SP-P	S G E ver	<10	Imp tiny <6 base	
	1.1 frag	110	1	Dark grey – dark reddish brown base	84	47	39	VP	S G	<6	Imp tiny <6 base	
	1	10050	1	Dark grey/blue – brownish orange patches – base dark reddish brown	339	285	105	L	S G E N	<15 <25	Imp <50 m<30 – base imp <5 few	
26/02/10 (5/6)	1.2	7280	1	Dark grey – dark red + brown patches	240	200	147	SP-P	S G	<8	Imp <25 top – imp + voids <60 base	p
	1.6	13590	1	Dark grey/blue – dark reddish brown patches	211		210	S-L	S G	<10 m<5	Imp + voids <20 – organic imp	
26/02/10 (6)	2.1	4150	1	Dark grey – dom dark reddish brown	122	274	133	P	S G	<3	Voids <40 m<30	
26/02/10 (7)	3	1120	1	Dark grey – dark red purple + orange patches	137	110	69	SP	S G	<9		p
	2.1	250	1	Dark grey – dark red patches	85			P	S G	<6	Imp <20	
	1.2	1480	1	Dark grey/black – dark brown	?			VP	S G	<3	Imp <30	
26/02/10 (8)	1.4	2310	2	Dark grey – dark red patches	154 85	143 67	93 57	S	S G	<11	Imp <28	p
	5	520	1	Dark grey – dom dark brown + orangey brown patches	124	102	47	SP	S G	<7		p
	5.1	410	10	Dark grey – dark brown + orangey brown + red patches	18-75			SP-P	S G	<6		p
	4	135	1	Dark grey shiny – dom dark brown + dark reddish orangey brown	82	61	33	P-VP	S G	<5 m<2		
27/02/10 (2)	1.1	2240	1	Dark grey – dark orangey reddish brown	190	156	76	SP-P	S G N	<10 <56		p
	2	551	1	Dark grey – dom dark reddish brown	112	112	48	SP-P	S G	<1	Voids + imp <20 m<15	
27/02/10 (3)	1 large	6060	1	Dark grey – dark brown + orange patches – dark brown base	284	226	110	S-SP	S G E	<16 <60	Imp <20 top – imp tiny base	p
	1.1	950	1	Dark grey – dark brown + red patches – dark	162	95	78	SP	S G	<6		

Location	Type (FS)	Weight	No	Colour	L	W	T	Porosity			Charcoal	M
									Shape	Size		
				reddish brown base								
	6	469	1	Dark grey/blue shiny – brownish orange base	115	85	37	P	S G	<7		
27/02/10 (4)	1	2610	1	Dark grey – dark brown + red patches - dark reddish orangey brown base	186	139	86	S-SP	S G E	<18 <32		
	2.1	430	2	Dark grey – dark brownish red patches	<94			P	S G	<6	Imp <13	
	6	191	4	Dark grey – orangey reddish brown	<60 102	53	53	VP	S G	<3	Imp <5	
27/02/10 (6)	5	720	1	Dark grey purple – black + dark brown	129	81	45	S-SP	S G I	<6		p
	5.1	980	1	Dark grey purple – dom dark yellowy orange red + brown	128	103	102	P	S G	<6	Imp <12	
Need pic	1.1?	550	1	Dark grey – orangey brown	126	101	47	SP-P	S G	<2	Imp <15	
27/02/10 (7)	5	1430	4	Dark grey purple – dark brownish red patches	59-163	47-139	23-41	SP	S G I	<5		p
	6	80	4	Dark grey – dark red + dark brownish red patches	<49			SP-P	S G I	<6		p
Need pic	1.1?	513	1	Dark grey – dark reddish brown	132	118	35	SP-P	S G	<3	Imp <30	
Need pic	2.1?	65	1	Dark grey/purple	75	44	20	SP-P	S G	<3		
20/09/09 (3)	1 thick	6640	1	Dark grey shiny – dom dark brown red + yellow orange patches	210	200	102	S	S G	<12	Imp <22	p

Key:

Porosity

S – solid SP – semi porous P – porous VP – very porous

Porosity shape

S – spherical G – globular E – elongated N – networked I – irregular

M – magnetism p – patches l - lump

Dom – dominated Imp – impressions Inc – Inclusions

Appendix C.2.1 – FS1

Characteristic features	Curved (convex) base, large plano-convex cakes, circular in plan, approximately 300mm in diameter, mostly solid to semi-porous
Size range	From fragments 60mm in length, 58mm in width and 52mm in thickness to more complete cakes up to 339mm in length, 285mm in width and 105mm in thickness.
Locations in which found	26/01/10 (8), 29/01/10 (2) (4), 30/01/10 (1) (2), 03/02/10 (1) (6) (14), 05/02/10 (3) (4), 06/02/10 (3), 08/02/10 (1) (2) (4) (6), 09/02/10 (6) (7), 11/02/10 (1), 13/02/10 (3) (15), 15/02/10 (2), 16/02/10 (2), 17/02/10 (1), 18/02/10 (1) (4) (6), 19/02/10 (1), 23/02/10 (3) (4), 24/02/10 (1), 26/02/10 (1) (3) (5), 27/02/10 (3) (4), 20/09/09 (3)

Furnace slags of type 1 are one of the most abundant sub-types. Their major diagnostic features are that they have curved (convex) bases and a flat top surface (plano-convex cakes). The majority of the slag pieces are fragmentary with most of their edges broken but some are more complete and all have at least part of their top or bottom surfaces remaining enabling identification. They appear on most occasions to have been circular in plan (or oval in some cases) with an average diameter around 300mm. Most fragments (with the exception of few) are solid to semi-porous in nature. These type 1 furnace slag cakes and fragments are found in locations: 26/01/10 (8), 29/01/10 (2) (4), 30/01/10 (1) (2), 03/02/10 (1) (6) (14), 05/02/10 (3) (4), 06/02/10 (3), 08/02/10 (1) (2) (4) (6), 09/02/10 (6) (7), 11/02/10 (1), 13/02/10 (3) (15), 15/02/10 (2), 16/02/10 (2), 17/02/10 (1), 18/02/10 (1) (4) (6), 19/02/10 (1), 23/02/10 (3) (4), 24/02/10 (1), 26/02/10 (1) (3) (5), 27/02/10 (3) (4), 20/09/09 (3).

The majority of the type 1 furnace slag are fragmentary with few remaining whole. The fragments and slag cakes range in size from 60mm in length, 58mm in width and 52mm in thickness to 339mm in length, 285mm in width and 105mm in thickness. Complete or almost complete cakes were recovered in locations 30/01/10 (2), 06/02/10 (3), 08/02/10 (1), 09/02/10 (7), 23/02/10 (3) and 26/02/10 (5). They all have similar dimensions ranging in maximum diameter from 280-339mm and in maximum thickness from 82-105mm. Although many of the other broken fragments attributed to this sub-type are broken with no natural edges remaining, many still retain one edge enabling them to be identified. Fragments from locations 29/01/10 (2), 30/01/10 (1) (2), 03/02/10 (1) (14), 05/02/10 (3) (4), 06/02/10 (3), 08/02/10 (1) (2) (4) (6), 09/02/10 (6) (7), 11/02/10 (1), 13/02/10 (15), 19/02/10 (1), 23/02/10 (3) (4), 26/02/10 (1) (3) (5), 27/02/10 (3) (4), 20/09/09 (3) have at least one natural edge remaining. Most appear to be similar in size and shape as the more complete cakes. However, there are a few exceptions which will be described separately at the end of this section.

All slag cakes and fragments of this sub-type are pale dark grey or dark greyish-blue in colour with patches varying in shades of dark red, purple, brown, orange and yellow. Very few fragments have shiny or crystallised surfaces. A few fragments appear to have a metallic sheen and crystallisation on fresh fractures. These are found in locations 30/02/10 (1), 05/02/10 (3), 09/02/10 (7), 19/02/10 (1) and 20/09/09 (3). The fragment from 05/02/10 (3) is very crystallised with large fayalite crystals apparent on the top surface which is fully broken. None of the type 1 furnace slag fragments and cakes are fully magnetic but ones found in locations 29/01/10 (4), 08/02/10 (1) (4), 09/02/10 (6) (7), 11/02/10 (1), 16/02/10 (2), 18/02/10 (1), 19/02/10 (1), 23/02/10 (3), 26/02/10 (1) (3), 27/02/10 (3), 20/09/09 (3) have some magnetic patches which suggests metallic iron content in those areas.

There are two main morphological categories of this type 1 furnace slag. The majority are thick fragments with well-defined convex undersides found in locations 26/01/10 (8), 29/01/10 (2) (4), 30/01/10 (1) (2), 03/02/10 (1) (6), 05/02/10 (3), 06/02/10 (3), 08/02/10 (1) (2) (4) (6), 09/02/10 (6) (7), 11/02/10 (1), 13/02/10 (3), 15/02/10 (2), 16/02/10 (2), 17/02/10 (1), 18/02/10 (1) (4), 19/02/10 (1), 22/02/10 (4), 23/02/10 (3) (4), 24/02/10 (1), 26/02/10 (1) (3) (5), 27/02/10 (3) (4), 20/09/09 (3). These vary slightly in surface morphology but appear to have been similar in shape and size. Their top surfaces are usually dominated by rough to very rough globular projections suggesting that the slag was well molten but viscous. These protrusions are mainly small to medium in size not protruding more than a few centimetres above the top surface. They are rounded flows of slag often coarse sandpaper rough to rough textured with very small sharp protrusions of material. They are also often broken in parts revealing some spherical porosity and leaving sharp edges which adds to the rough appearance and texture of the top surfaces. On many of these fragments there are clear charcoal impressions up to 50mm in size (most <30mm) nested in between these bulbous projections. It is possible that charcoal lumps aided the formation of these projections by keeping slag separated on the surfaces. In any case they also add to the rough and agitated appearance.

29/01/10 (2)

30/01/10 (2)

30/01/10 (2)

08/02/10 (1)

08/02/10 (4)

08/02/10 (4)

08/02/10 (6)

09/02/10 (6)

13/02/10 (3)

26/02/10 (5)

27/02/10 (3)

27/02/10 (4)

Fragments found in locations 26/01/10 (8), 30/01/10 (1), 05/02/10 (3), 08/02/10 (2), 24/02/10 (1) and 26/02/10 (3) have abraded or broken surfaces which have left sharp protrusions. It is likely though that these surfaces also had bulbous projections but broke off after deposition.

26/01/10 (8)

05/02/10 (3)

08/02/10 (2)



30/01/10 (1)

However, some fragments are less bulbous with smoother (mid rough) almost rippled/crimpled top surfaces. These are present in locations 06/02/10 (3), 08/02/10 (4), 11/02/10 (1), 17/02/10 (1), 18/02/10 (1), 23/02/10 (3) (4) and 20/09/09 (3). The ripples on these fragments and cakes resemble those found on tap slag except that there is no clear directional flow and they are for the most part wider suggesting that the slag was less viscous. Most of these also have few charcoal impressions up to 22mm but mostly <15mm in size. In some examples the top crust has broken in parts revealing spherical or globular voids.

06/02/10 (3)

11/02/10 (1)

23/02/10 (3)

23/02/10 (4)

20/09/09 (3)

08/02/10 (4)

Fragments in locations 03/02/10 (1), 08/02/10 (1), 16/02/10 (2), 19/02/10 (1) and 26/02/10 (1) on the other hand are just rough in texture. These surfaces are less agitated than the ones with bulbous projections but are still rough with very small to small sharp protrusions of material. Most of these also have some charcoal impressions <35mm in size which add to the rough texture. The surfaces for the most part are more intact (solid) than the bulbous or rippled slags with no to very few small spherical voids.

03/02/10 (1)

16/02/10 (2)

19/02/10 (1)

26/02/10 (1)

All the bottom surfaces are evenly curved (convex) with no or very few protrusions of material. The majority are medium to coarse sandpaper rough in texture with very small sharp protrusions left by impressions of stones or charcoal. These small charcoal impressions which dominate most of the slag cake and fragment undersides are <12mm in size with most being <6mm. In some cases this layer has partially chipped off leaving thin flaky layers of material on the surfaces. Most bases are solid but some fragments have many small spherical voids on the surface adding to the sandpaper rough texture while others have few stone inclusions mainly <5mm in size. For the most part the bottom surfaces have a slightly different colouration than the top surfaces. The majority vary in shades of dark reddish-orangey-brown.

The exceptions are found in locations 26/01/10 (8), 29/01/10 (4), 03/02/10 (1) (6), 08/02/10 (1) (2), 11/02/10 (1), 15/02/10 (2) and 17/02/10 (1). These have undulated bases similar to the undersides of tap slags. These are smooth, small undulations formed by the moulding of the slag around small stones. These surfaces are smooth to low sandpaper rough and in some cases like the fragments from 26/01/10 (8), 03/02/10 (1) and 11/02/10 (1) there is a thin layer of soil (or maybe remains of clay) leaving a low to medium sandpaper rough texture. Most of these undulated bases are dark grey in colour but there are some patches of varying shades of grey, orange, red and brown.

29/01/10 (4)

03/02/10 (6)

15/02/10 (2)

08/02/10 (1)

As mentioned above the majority of the type 1 furnace slags are fragmentary dominated by broken edges which reveal a good cross-section of the slags. These indicate that most are solid to semi-porous in nature with mainly spherical and globular voids up to 30mm (most <10mm) spread randomly throughout their thickness. Although the voids are randomly spread there are greater concentrations of larger voids closer to the top surface of the slag cakes. This is especially true of the ones with bulbous agitated top surfaces. Many also have a few horizontally elongated voids up to 91mm in size (most <30mm) while fragments from locations 08/02/10 (6), 16/02/10 (2) and 18/02/10 (6) also have a few vertically aligned ones up to 30mm in length. The horizontally elongated voids are mainly present towards the top parts of the slags whereas the vertically elongated ones are concentrated in the centre and top of the slags. There are a few fragments which are more porous. The examples in locations 29/01/10 (4), 03/02/10 (6), 08/02/10 (1), 18/02/10 (4) and 23/02/10 (4) are semi-porous to porous while the fragments from location 09/02/10 (7) are very porous. The voids in these cases dominate the whole section of the slags. In the case of the fragments from 09/02/10 (7) the voids have left very thin layers of slag in between giving them an almost honeycomb appearance.

08/02/10 (1)


09/02/10 (7)


09/02/10 (7)

The fragments recovered from locations 03/02/10 (14), 05/02/10 (3) (4), 13/02/10 (15) and 18/02/10 (4) (6) are slightly different than the slags described above and deserve special mention. They vary in size from about 90mm in maximum length to the largest fragment 370mm in length, 275mm in width and 70mm in thickness. Most of these are fragmentary with most edges broken but the fragment from 03/02/10 (14) and the largest fragments from 05/02/10 (4) and 13/02/10 (15) appear to be more complete (approximately 1/2 to 3/4 remaining of their estimated original size) with some of their natural edges reasonably intact. They all have very rough agitated top surfaces with bulbous small to medium projections of material similar to the majority of the type 1 furnace slag cakes discussed above. These top surfaces also have some charcoal impressions up to 35mm but mostly <25mm in size adding to the rough appearance. Most surfaces are reasonably solid but there are a few spherical voids apparent where the bulbous projections have broken.

Their bases are also similar with a well-defined convex shape dominated by very small stone and charcoal (<7mm) impressions. The fragment from 05/02/10 (3) appears to have a more undulated bottom surface. All the bases are solid with no or very few small spherical voids and are dominated by dark orangey-brown or dark brownish-red colouring. The major differentiation between the type 1 furnace slag fragments discussed above is that these fragments appear thinner on the whole with thicknesses not more than a few centimetres. They look like thinner rounded fragments that may have solidified on the inner parts of the furnace walls but their convex curvature (in all directions) and charcoal impressions on their bottom surfaces suggests that they most likely solidified at the base of the furnace. Since the majority are very fragmentary it is difficult to judge the original size of these cakes but the curvatures give an indication. Most appear to have been similar to the ones discussed above at about 300mm in diameter but the cakes from 13/02/10 (15) seem much larger and would likely have had a diameter in excess of 400mm.

The fragments range in porosity from solid to porous usually with the bottom parts more solid and the top parts with greater porosity. These voids are mainly spherical or globular in nature <16mm in size but there are some elongated voids in the examples from 13/02/10 (15) and 18/02/10 (6) up to 30mm in size. None of the slag fragments are fully magnetic but the ones in locations 03/02/10 (14) and 18/02/10 (4) have some magnetic patches suggesting that they have areas with metallic iron content.

03/02/10 (14)


05/02/10 (3)


05/02/10 (4)

13/02/10 (15)

13/02/10 (15)

18/02/10 (4)

18/02/10 (6)

Appendix C.2.2 – FS1.1

Characteristic features	Mostly agitated bulbous top surfaces, curved (convex) bases often with a crust, porous to very porous (honeycomb) in nature.
Size range	From the smallest fragment 84mm in length, 47mm in width and 39mm in thickness to the largest cake 323mm in length, 292mm in width and 130mm in thickness.
Locations in which found	03/02/10 (4), 06/02/10 (2) (3), 08/02/10 (1) (9), 12/02/10 (1), 13/02/10 (2) (3), 16/02/10 (4) (6), 22/02/10 (3), 23/02/10 (1) (2) (5), 26/02/10 (5), 27/02/10 (2) (3) (6) (7)

Several type 1.1 furnace slag fragments were recovered. The major characteristic features that define this type are their agitated bulbous top surfaces, curved (convex) bases often with a crust and porous to very porous nature. Slags of this type were found in locations 03/02/10 (4), 06/02/10 (2) (3), 08/02/10 (1) (9), 12/02/10 (1), 13/02/10 (2) (3), 16/02/10 (4) (6), 22/02/10 (3), 23/02/10 (1) (2) (5), 26/02/10 (5) and 27/02/10 (2) (3) (6) (7).

Most of the slags in this type are fragmentary with broken edges on all sides but there are two almost complete plano- convex cakes found in locations 12/02/10 (1) and 16/02/10 (6). Some of the fragments from 03/02/10 (4), 08/02/10 (9), 13/02/10 (2) (3), 23/02/10 (1) and 27/02/10 (2) also have at least one surviving natural edge. All fragments have parts of their top or bottom surfaces remaining enabling identification. The slag fragments and cakes range in size from the smallest fragment 84mm in length, 47mm in width and 39mm in thickness to the largest cake 323mm in length, 292mm in width and 130mm in thickness. All broken fragments appear to have been part of larger plano-convex cakes probably similar to those better preserved ones found in the locations mentioned above.

All the slags are dark grey in colour but all have different coloured patches. These patches vary in shades of dark red, brown and orange. Their undersides also tend to be dominated by dark brownish-red or orangey-brown colouration. The fragments from 03/02/10 (4), 06/02/10 (2) and 23/02/10 (2) have shiny dark grey fractures which reveal crystallised surfaces with large fayalite crystals. The fragment from 06/02/10 (2) is missing the entirety of its original top surface revealing an almost fully crystallised interior with irregular or angular voids in between groups of adhering crystals. The fragments and cakes from locations 03/02/10 (4), 06/02/10 (2) (3), 08/02/10 (1), 13/02/10 (3), 16/02/10 (4), 23/02/10

(1) (2) (5) and 27/02/10 (2) are magnetic in parts while the fragments from 08/02/10 (9) are magnetic on the majority of their surface area. This suggests that most fragments have concentrations of metallic iron.

The top surfaces of these type 1.1 furnace slag fragments and cakes are all similar. They are dominated by small to medium agitated bulbous projections of slag. The majority are very rough with agitated and broken protrusions leaving sharp angular fractures on the surface. These breaks reveal some porosity in the form of spherical and globular voids (up to 30mm in size). Some of these surfaces almost look to have been crimpled with folds of slag bunching or overlapping one another. Many of the fragments and cakes also have some charcoal impressions up to 40mm but mostly <30mm in size. These add to the rough texture and appearance of the surfaces.

Some fragments are medium to rough with less agitated and more complete top surfaces. These are found in locations 06/02/10 (3), 08/02/10 (9), 12/02/10 (1) and 13/02/10 (3) and are dominated by flatter rounded ripples. The ripples do not appear to have flown in any particular direction but are randomly spread suggesting that the slag pooled. They also have a certain degree of surface crimpling whereby a thin layer of slag has bunched together forming very small folds on the surface a bit like the skin on milk.

The bottom surfaces are all similar. They are all evenly curved (convex) with no major protrusions of material. They all consist of a thin crust usually around 3-10mm in thickness which has partially chipped away on all fragments revealing a very porous honeycomb slag underneath. The crust on most examples is solid and dark brownish-red or orangey-brown in colour. The surfaces are medium to rough sandpaper rough in texture covered by very small sharp protrusions of material. These seem to have been created by numerous small impressions. Although on some fragments it is not clear what these imprints could have been on most they are clearly of very small charcoal (<17mm but mainly <6mm). Some fragments also have very small stone or quartz (mostly <5mm) inclusions adhering to the surface. One of the fragments from 08/02/10 (9) has a larger elongated oval/cylindrical protrusion (approximately 100mm long and 40mm wide) on its base meaning that there must have been a small depression on the furnace base which then got filled by slag. It is possible that this was caused by the racking of the furnace base with a stick to free a blockage of slag enabling the liquid slag to be tapped out of the furnace.

Since the majority of the slag fragments and cakes of type 1.1 furnace slag have broken edges and surfaces, a good cross section can be seen. These reveal that they are all porous to very porous in nature. The main parts of the slags are dominated by spherical and globular voids with a few irregular ones. These voids are up to 30mm but the majority are <12mm in size. Some examples in locations 08/02/10 (9), 16/02/10 (6), 23/02/10 (1) and 27/02/10 (2) also have some elongated or networked voids up to 60mm in length. The sheer quantity of these voids gives the slags a honeycomb like texture which is the primary characteristic of this furnace slag type. This is particularly well seen on the bottom surfaces where the more solid crust has chipped off revealing larger voids randomly spread throughout the section with many smaller voids covering the rest of the surface area. In some instances only very thin layers/flanges of slag separate the voids.

03/02/10 (4)

03/02/10 (4)

06/02/10 (2)

06/02/10 (3)


08/02/10 (9)


08/02/10 (9)


12/02/10 (1)


12/02/10 (1)

13/02/10 (2)

13/02/10 (3)

16/02/10 (4)

16/02/10 (6)

22/02/10 (3)


23/02/10 (1)


23/02/10 (2)


23/02/10 (5)


26/02/10 (5)


27/02/10 (2)

Two fragments deserve special mention due to their unusual morphological properties. The fragment from 08/02/10 (1) is interesting because it appears to be the remains of a bottom surface crust that has become detached from the main bulk of the slag. It is thin (not more than 16mm thick) and up to 206mm in maximum length. The base is evenly curved with the similar very small impressions described above making it medium to rough sandpaper rough in texture. The interior (or top part) appears to have been broken with many small protrusions of material with clear fractures. The crust is solid to semi-porous with some spherical and globular voids <6mm.




08/02/10 (1)

The second fragment was recovered from location 16/02/10 (6). It is 119x63x74mm in size and is very similar to the other fragments described above with a bottom surface sandpaper rough crust and a very porous honeycomb consistency. About half of the fragment has broken surfaces and only one side and a part of the underside remains. The main interesting feature is this one surviving side which displays an even moulded convex curve as if it had solidified against the furnace wall. This side is more solid looking with a medium rough thin slag crust which has chipped off in some places revealing some irregular and spherical voids up to 10mm. The crust has a more molten appearance than the rest of the slag.

16/02/10 (6)

Appendix C.2.3 – FS1.2

Characteristic features	Plano-convex cakes, circular plan, small diameter (200-250mm)
Size range	From the smallest fragment 73mm in length, 66mm in width and 72mm in thickness to the largest cake 250mm in diameter (length and width) and 150mm in thickness
Locations in which found	26/01/10 (7), 30/01/10 (2), 01/02/10 (4) (5), 02/02/10 (5), 03/02/10 (14) (15), 05/02/10 (6), 08/02/10 (2) (5) (10), 09/02/10 (2), 10/02/10 (1), 11/02/10 (1) (6), 12/02/10 (1) A3 A8 (3), 19/02/10 (4), 26/02/10 (5) (5/6) (7)

Type 1.2 slags are one of the most abundant sub-types of furnace slags. Their major characteristic features are that they are all plano-convex cakes, mostly circular in plan with a small 200-250mm diameter. Slags of this type are found in locations 26/01/10 (7), 30/01/10 (2), 01/02/10 (4) (5), 02/02/10 (5), 03/02/10 (14) (15), 05/02/10 (6), 08/02/10 (2) (5) (10), 09/02/10 (2), 10/02/10 (1), 11/02/10 (1) (6), 12/02/10 (1) A3 A8 (3), 19/02/10 (4) and 26/02/10 (5) (5/6) (7).

Many of the slag cakes are almost complete with only minor fracturing on the edges. Fully fragmentary examples with all edges broken are found in locations 26/01/10 (7), 05/02/10 (6) and 10/02/10 (1). Although they are broken their curvatures and general morphological aspects suggest that they would have been of this small plano-convex furnace slag type. Broken fragments are also found in locations 01/02/10 (4) (5), 02/02/10 (5), 03/02/10 (14) (15), 05/02/10 (6), 08/02/10 (2) (5) (10), 09/02/10 (2), 12/02/10 (1) A3 A8 (3) and 26/02/10 (5) (7) but these have a significant proportion of their natural edges remaining. Most appear to be between 1/2 and 4/5th complete allowing them to be characterised as this type. The fragments range in size from the smallest fragment 73mm in length, 66mm in width and 72mm in thickness to the largest cake 250mm in diameter (length and width) and 150mm in thickness.

Slags of this type are dark grey in colour but have many different coloured patches dominating their surfaces. These patches vary in shades of light to dark grey, brownish-orange, brownish-red and dark red/purple. None of the slags are crystallised or particularly shiny being primarily dull coloured. The majority have some magnetic areas which seems to correlate with some of these orangey and red patches suggesting that in some parts they contain metallic iron. The only exceptions that are not magnetic are found in locations 26/01/10 (7), 30/01/10 (2), 01/02/10 (4), 08/02/10 (2), 11/02/10 (6) and 26/02/10 (5) (7).

As mentioned above, all type 1.2 slags are plano-convex with reasonably flat top surfaces and curved convex bases. The only exception is found in location 01/02/10 (5). This example has a large, deep (approximately 100mm) depression taking up the majority of the top surface area. It has steep sides that rise evenly from the central depression to form a sort of bowl shape. One of the fragments from 02/02/10 (5) also has a small central depression in the top surface approximately 90mm wide and 50mm deep. The majority of the slags are roughly circular in plan with evenly curved and well defined edges. However, a few fragments and cakes from locations 08/02/10 (5) (10), 11/02/10 (1), 12/02/10 (1 – A8) and 19/02/10 (4) are not perfectly circular with edges less well defined. This may be due to the fact that most of their edges have broken but could also suggest that they did not consolidate and solidify evenly at the bottom of the furnaces. In the case of the cake from 19/02/10 (4) which is reasonably complete and more oval (elongated) in shape it is likely that the bottom surface of the furnace was not uniformly circular.

The top surface morphology of the type 1.2 furnace slag fragments and cakes varies considerably. The majority (in locations 30/01/10 (2), 01/02/10 (4) (5), 02/02/10 (5), 08/02/10 (5) (10), 09/02/10 (2), 10/02/10 (1), 12/02/10 (1) A3 A8, 19/02/10 (4) and 26/02/10 (5) (5/6) (7) are rough to very rough with small to medium sharp protrusions of material. Some appear to be more agitated than others but for the most part they are reasonably flat with only small bumps and dips adding some relief to the surfaces. Many of these rough surfaces have charcoal impressions up to 58mm but mostly <25mm in size adding to the rough texture. The examples from 01/02/10 (5), 02/02/10 (5) and 10/02/10 (1) appear to have larger charcoal impressions. The projections are sometimes broken revealing some small spherical and globular voids but on the whole the top surfaces are solid. The only exceptions are the cakes from 26/02/10 (5) and (7) which have broken top surfaces dominated by spherical (<10mm) voids. This gives the surfaces an almost honeycomb texture with thin sharp flanges of slag in between the gas voids. The cake from 01/02/10 (4) is interesting due to the fact that it has a large rough protrusion on the top surface. This lump is rises approximately 80mm from the surface covering half of the surface area. It is dominated by charcoal impressions and small sharp broken protrusions.



30/01/10 (2)



01/02/10 (4)



02/02/10 (5)

12/02/10 (1 – A3)



21/09/09 (6)

Some of the cakes found in locations 26/01/10 (7), 03/02/10 (15), 08/02/10 (2) and 11/02/10 (1) have small to medium agitated bulbous protrusions. These are rounded protrusions almost tendril-like slag which have smaller sharp projections rising from them. These give the surfaces a very rough texture. In between these there are often charcoal impressions up to 50mm but mostly <25mm in size adding to the roughness. Some of these protrusions are broken revealing some porosity beneath in the form of small spherical and globular voids. The largest cake which is found in 26/01/10 (7) has flatter medium rough slag on the edges of the top surface with the more agitated bulbous protrusions concentrated in the centre.


26/01/10 (7)


03/02/10 (15)

Some of the cakes from locations 02/02/10 (5), 05/02/10 (6) and 12/02/10 (1 – A8) (3) have wider rounded projections or rippled top surfaces. These do not appear to have any particular flow direction suggesting that the slag pooled. The surfaces are still rough as there are small sharp protrusions of material rising from the more rounded surface relief. The cakes from locations 03/02/10 (14) (15) and 11/02/10 (6) also have rounded (almost like large undulations) top surfaces but are mid rough to coarse sandpaper textured with many very small sharp protrusions. Like the rougher surfaces described above these examples also have solid top surfaces with only minor porosity present where the surface has chipped/broken off. All have some charcoal impressions present on their top surfaces up to 50mm in size. The largest fragment from 05/02/10 (6) has a crimpled top surface with small slag folds like the skin on milk. There are also some small quartz crystals (<5mm) present on the surface giving it a rough texture.

02/02/10 (5)


05/02/10 (6)


03/02/10 (15)

12/02/10 (1 – A8)

12/02/10 (1 – A8)

The bottom surfaces also vary greatly in morphology. All are convex which suggests that they solidified at the bottom of the furnaces but very few are even (like the type 1 and 1.1 slags) with more protrusions present. Many appear to have rough gritty imprinted bottom surfaces. These are found in locations 26/01/10 (7), 02/02/10 (5), 03/02/10 (14) (15), 08/02/10 (5), 10/02/10 (1), 11/02/10 (6), 12/02/10 (1 – A3) (1 – A8) and 26/02/10 (5). These are primarily rough with many very small sharp protrusions of material giving the surfaces a very rough gritty texture. The exception is the fragment from 26/02/10 (5) which is medium rough with smaller and less sharp protrusions and very small charcoal impressions (<6mm). Some of these imprinted surfaces are partially broken like in the examples from location 02/02/10 (5) while others have more uneven surfaces with medium sized rounded protrusions giving some relief. The more uneven bases are found in 26/01/10 (7), 08/02/10 (5), 12/02/10 (1 – A8) and 26/02/10 (5). Most of these gritty surfaces do not appear to have charcoal impressions (with the exception of the one in 26/02/10 (5)) but there are some small stone inclusions (<10mm but mostly <5mm) on most but especially on the ones from 03/02/10 (14) (15) and 08/02/10 (5). Due to the high quantity of adhering stones it is possible that these may have been in contact with clay material.

03/02/10 (14)

03/02/10 (14)

12/02/10 (1 – A8)

26/02/10 (5)

Others are either undulated with many small rounded protrusions or have a mixture of undulations and the imprinted gritty surfaces described above. These surfaces are mostly dominated by either small stone (mostly <5mm) or charcoal impressions up to 40mm but mostly <10mm in size. The more undulated surfaces are mid rough and found on fragments in locations 08/02/10 (10) and 26/02/10 (7). The surfaces with a mixture of undulations and rougher gritty material are mid to rough in texture and found in locations 30/01/10 (2), 01/02/10 (4) (5), 05/02/10 (6), 09/02/10 (2), 12/02/10 (1 – A8) and 19/02/10 (4). The grittier parts often have small stones inclusions adhering giving the surfaces either a rough texture or coarse sandpaper texture. The undulations are also not always well rounded but sometimes have sharp almost angular edges. Most of these bottom surfaces are reasonably solid with few fractures and spherical gas voids.

08/02/10 (10)

19/02/10 (4)

Some examples have bottom surfaces dominated by larger charcoal impressions and voids. The surfaces are often uneven and/or broken due to these. Good examples are found in locations 01/02/10 (5), 02/02/10 (5), 11/02/10 (1), 12/02/10 (3) and 26/02/10 (5-6). The examples from 01/02/10 (5) and 26/02/10 (6) are very similar. The cakes are of a similar shape and size. They are both dense and have very rounded but broken bottom surfaces dominated by large charcoal voids up to 60mm in size. These voids have pronounced medium protrusions of slag in between which appear to be mostly broken revealing a semi-porous slag with many small spherical gas voids. These breaks and voids have left sharp edges making the bases rough in texture. The other fragments in locations 02/02/10 (5), 11/02/10 (1) and 12/02/10 (3) have more complete molten surfaces. They are made of many small rounded protrusions that were shaped by the numerous charcoal impressions (<25mm) in between. The sheer quantity of these protrusions and angular charcoal voids give the slags a rough to very rough texture. In addition, some of the cakes appear to have thin flakes of slag on parts of their bottom surfaces (especially within the angular charcoal impressions) adding to the roughness. Cakes from 11/02/10 (1) and 12/02/10 (3) are particularly flaky and uneven.

01/02/10 (5)

11/02/10 (1)

12/02/10 (3)

26/02/10 (5/6)

Of special interest is the bottom surface of the large cake from 08/02/10 (2). It is entirely covered in dark grey reduced and vitrified coarse clay. This clay is dominated by quartz crystals up to 12mm but mostly <5mm in size. The surface is very even with no major protrusions but it does appear to be broken. Many small spherical voids (<8mm) are present on the surface especially where the clay is more vitrified. This broken clay layer gives the base a coarse sandpaper texture. The shape of this cake's base is also interesting as it differs from all other examples. It is almost conical in shape with a snub nose rounded extremity. It is likely that the base of the furnace was lined with clay leading to the furnace slag that pooled at the bottom to fuse with it. Not much adhering clay remains were noticed on any other fragment and cake of this type except some in locations 26/01/10 (7), 30/01/10 (2), 01/02/10 (5), 02/02/10 (5), 26/02/10 (5/6) and 21/09/09 (6) which have small areas where reduced or vitrified coarse clay remains. These are usually on the edges of the cakes which must have been in contact with the furnace wall. The clay appears to be coarse in most examples dominated by quartz crystals mainly <5mm in size.


08/02/10 (2)

A few other cakes from locations 01/02/10 (5), 08/02/10 (5) and 26/02/10 (7) disserve special mention. The bases on these have large elongated protrusions on their undersides. These may have been caused by the intentional prodding of the furnace base to release blockages enabling the tapping of slag. It is especially convincing on the example from 01/02/10 (5) which as mentioned earlier has a large top surface dip. It is possible that this dip was created by the drainage of slag through tapping. In any case it suggests that the base of the furnaces were not perfectly evenly rounded but had some elongated depressions.


01/02/10 (5)



08/02/10 (5)

26/02/10 (7)

Most fragments and cakes of this type have broken edges revealing a cross section through their thickness. These show that the majority of the cakes are solid to semi-porous in nature with some randomly distributed spherical and globular voids (<16mm but mostly <7mm). The cakes from locations 01/02/10 (5), 03/02/10 (15), 05/02/10 (6), 08/02/10 (10), 09/02/10 (2), 11/02/10 (1), 12/02/10 (1) A8, 19/02/10 (4) and 26/02/10 (5) (5/6) (7) are semi-porous to porous with greater quantity of small spherical and globular voids up to 18mm but mostly <10mm in size. The cake from 26/02/10 (7) is very porous with a broken top surface showing honeycomb porosity underneath. Once again the porosity does not seem to concentre in any particular areas of the cakes but are mostly randomly spread. The exception is the example from 26/02/10 (7) which has the majority of its porosity on its top surface with the rest of the slag being reasonably solid. Very few elongated/flattened voids were noticed but horizontal ones were present in the examples from 01/02/10 (5), 05/02/10 (6) and 12/02/10 (1 – A8). Vertical elongated voids were also present in the cakes from 01/02/10 (4) and 26/02/10 (5). These voids were usually few and up to 50mm but mostly <22mm in length.

Two type 1.2 furnace slag cakes found in locations 26/01/10 (7) and 11/02/10 (6) need special mention. These have what appears to be tool marks on their upper surfaces. Large linear impressions are present on these cakes. These impressions are flat and appear to have smeared the slag. This, along with the fact that the rest of the surfaces are rough suggests that they did not occur naturally. In the example from 26/01/10 (7) there are two clear linear marks up to 50mm in width, stretching the entirety of the top surface. On the cake from 11/02/10 (6) there are three or four linear impressions approximately 15mm wide and 70mm in length creating a depression in the surface approximately 40mm deep, 65mm wide and 110mm in length. These surface impressions may have been created at the end of the smelt when the bloom was retrieved from the furnace. It suggests that the blooms where removed when the slag was still partially molten and the furnaces still hot.

26/01/10 (7)

11/02/10 (6)

Another interesting feature is found on one of the cakes from 02/02/10 (5). This example has a very large greyish-white patch covering approximately half of its top surface. This patch is sandy or gritty in texture and seems fused to the slag. It may be an area which contains more burnt charcoal ash but could also be evidence for the addition of a flux to the smelting process. Texture and colour wise it resembles limestone which is a common flux added to the bloomery process.

02/02/10 (5)

Appendix C.2.4 – FS1.3

Characteristic features	Concavo-convex profile, circular plan, mid rough top surface with few protrusions, base dominated by adhering reduced clay
Size range	From the smallest fragment 165mm in length, 144mm in width and 54mm in thickness to the largest 287mm in length, 255mm in width and 80mm in thickness
Locations in which found	01/02/10 (6), 02/02/10 (1), 08/02/10 (5) and 25/02/10 (1)

There are very few fragments and cakes of type 1.3 furnace slag. Their major characteristic features are that they are concavo-convex in profile, circular or oval in plan, have medium rough top surfaces with few protrusions and that their bottom surfaces are dominated by adhering reduced clay. The majority of the type 1.3 furnace slag fragments were recovered from location 02/02/10 (1) but individual fragments were also recovered from locations 01/02/10 (6), 08/02/10 (5) and 25/02/10 (1). However, the cake from 25/02/10 (1) differs slightly from the other examples and will be described separately at the end of this section.

All type 1.3 furnace slags are fragmentary with most having broken edges along their entire periphery. A few fragments in location 02/02/10 (1) appear to be almost complete but still have broken edges on most of their sides. All examples have surviving top and bottom surfaces enabling them to be characterised as this type. The fragments and cakes range in size from the smallest fragment 165mm in length, 144mm in width and 54mm in thickness to the largest 287mm in length, 255mm in width and 80mm in thickness. They all have a concavo-convex profile and seem to have been spherical or oval in plan with an original maximum diameter of around 300mm.

All slag fragments and cakes are dark grey in colour but most have different coloured patches varying in shades of mid to dark grey, dark brownish-red and yellowy-orange. The fragments/cakes in locations 01/02/10 (6) and 25/02/10 (1) are more of a dark greyish-purple. None of the slags show crystallisation and the colourations are dull. All examples except the one from 01/02/10 (6) are magnetic in parts suggesting that there are areas of more metallic iron content.

The top surfaces are all even with very few to no medium or large projections of material. These are medium rough in texture with many very small to small sharp protrusions of material. All examples also have concavo top surfaces with clear shallow depressions. These depressions are not abrupt but have gentle slopes from the surviving edges of the cakes reaching the lowest point in the centre of the surface (or at least in the presumed centre for the more fragmentary examples). Some cakes have smoother areas where the slag appears to have been more molten. These smoother areas either have very small rounded protrusions or are almost flat and rough sandpaper in texture. It is worth mentioning that one example in location 02/02/10 (1) has a smoother sandpaper rough area which looks like a streak on the surface about 50mm wide and running the whole length of the surface. It is interesting because the slag around this streak appears rougher with small sharp protrusions. It may represent a tool mark whereby an implement raked the top surface. The fragment from 01/02/10 (6) does not seem to have any charcoal impressions but this may be due to a high surface tension. On the other hand all the others have clear randomly situated charcoal impressions up to 40mm but mainly <12mm in size. These add to the rough texture of the slags. Most examples have solid top surfaces with no to very few spherical or globular voids.

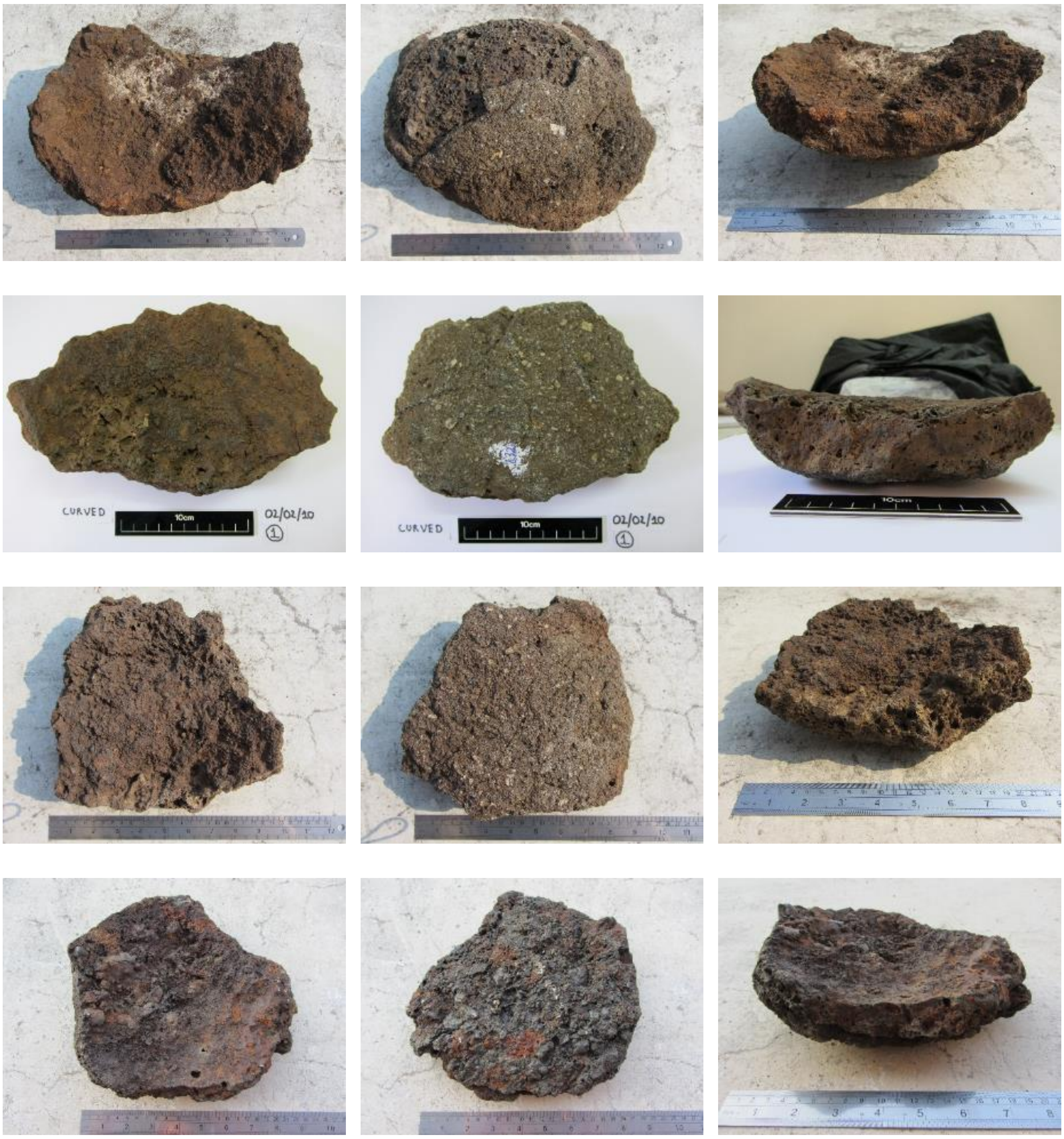
The bottom surfaces are interesting due to the fact that the majority (with the exception of two examples) have adhering medium to dark grey reduced clay. This clay seems to dominate the majority of the surface in most examples but there are areas where it has chipped off. These clay layers are broken and usually between 5 and 18mm thick. The majority of the clay appears to be coarse in nature with many quartz crystals up to 8mm but mostly <4mm in size. In some of the examples from 02/02/10 (1) there is a thin vitrified layer in between the slag and reduced clay. In order for this reaction to occur the slag must have adhered to the furnace lining while in a molten hot state. The presence of clay on the base of these concavo-concave cakes is interesting as it suggests that they solidified either against the furnace wall or that since they all have convex bases (with curvature in all directions) that the furnace bases were lined with clay. On some fragments this adhering clay has chipped off revealing a rough almost undulated base. In the largest fragment from 02/02/10 (1) the clay has chipped off to reveal a more porous vitrified surface dominated by small spherical and globular voids. This surface is still convex with no major protrusions but the breaks have left small sharp edges making it rough to the touch.

The two exceptions without clay adhering to the base are found in locations 02/02/10 (1) and 25/02/10 (1). It is possible that they once had adhering clay but it may have become detached after deposition. Their bases are still evenly convex with few or no porosity. These surfaces are medium to rough with small sharp undulations. These undulations or small pits may have been caused by larger quartz crystals in a clay lining but it cannot be ascertained. In support however is the fact that where the clay has chipped off on the base of the fragments discussed above the surfaces display a similar rough undulated surface. The fragment from 25/02/10 (1) has a few small charcoal impressions up to 10mm in size adding to the rough texture. Due to this, it seems doubtful that this fragment ever had adhering clay.

Since all type 1.3 furnace slag fragments and cakes have broken edges, it reveals a good cross section through their thickness. The fragment from 01/02/10 (6) is solid to low in porosity with very few small spherical and globular voids mostly <1mm in size. It is however fractured in several places with long, linear and thin fractures running through the cake. A few examples in 02/02/10 (1) are also more solid in nature but the majority of the cakes and fragments are low to semi-porous with randomly situated spherical and globular voids <12mm in size. A few examples in location 02/02/10 (1) also have networked voids up to 37mm in size. Most of the top and bottom surfaces are solid in nature.

01/02/10 (6)


02/02/10 (1)



25/02/10 (1)

The furnace slag from 08/02/10 (5) differs from the other fragments and cakes in this type. It is 271x185x99mm in size and concavo-convex in profile. It is oval in shape with one pinched end forming a sort of tear or pear shaped plan. It is a complete furnace slag cake that is different from anything seen yet. The pointed end has a broken fracture and it is very likely that this was where the slag was tapped which would explain the elongated tear shape. The slag itself is greyish-blue but is covered in mid to dark grey and dark brownish-red colouring.

The top surface has a depression like a bowl shape which is partially filled with a very rough amalgamation of slag which extends all the way to the pointy end. This large projection of slag has many small sharp projections of material with lots of charcoal impressions (mostly <12mm but as big as 30mm) and some spherical and irregular voids (<5mm). The projection is magnetic in some areas especially where there is a dark reddish colouring which is likely to be oxidisation. This large projection is not as dominant on the more rounded end of the cake where the depression is partially free of slag with a depth of approximately 55mm.

The sides of the bowl appear well molten with rounded projections but still rough in texture with a few charcoal impressions. The rim varies in size from approximately 28-35mm in width. It is mainly sandpaper rough and has some remains of reduced clay. This clay continues from the edge of the rim and covers the majority of the underside of the slag cake. It seems to have reacted with the slag and approximately 10mm of it remains as a crust stuck to the underside (some of this crust is starting to chip off and there are some cracks apparent). It is all dark grey reduced clay coarse to very coarse in fabric with many small to medium size quartz inclusions. These vary in size from <1mm to 9mm. The underside is well rounded (convex) and must have formed at the bottom of a clay lined furnace.

The broken parts reveal that the slag is of medium porosity with some randomly situated spherical voids <4mm in size. This example shows that the inner diameter of the furnace must have been at least 190mm and perhaps as much as 280mm. The shape of the slag is not circular which means that the depression at the bottom of the furnace was not circular but this does not mean to say that the furnace structure was not.




08/02/10 (5)

Appendix C.2.5 – FS1.4

Characteristic features	Small plano-convex cakes, circular in plan, <200mm diameter, rough top surface, curved and rough/sandpaper rough base
Size range	From the smallest fragment 85mm in length, 67mm in width and 57mm in thickness to the largest cake 182mm in length, 167mm in width and 59mm in thickness
Locations in which found	08/02/10 (1) (9), 13/02/10 (13), 19/02/10 (5), 26/02/10 (8)

Very few type 1.4 furnace slag fragments were recovered. Their main characteristic features are their plano-convex profile, circular plan, small <200mm diameter, rough top surface and their curved rough/sandpaper rough base. These small cakes and fragments were found in locations 08/02/10 (1) (9), 13/02/10 (13), 19/02/10 (5) and 26/02/10 (8).

The majority are broken to some extent but some cakes from 08/02/10 (1) (9) and 26/02/10 (8) seem almost complete with only minor fracturing on their edges. The fragment from 13/02/10 (13) and the largest from 19/02/10 (5) also have one natural edge remaining even though all other edges are broken. All type 1.4 furnace slags have at least their top and/or bottom surfaces remaining. They range in size from the smallest fragment 85mm in length, 67mm in width and 57mm in thickness to the largest cake 182mm in length, 167mm in width and 59mm in thickness. They appear to have been smaller plano-convex cakes than the ones described above. The curvatures point to diameters of <200mm and this is the primary characteristic of these type 1.4 furnace slags.

All type 1.4 slags are dark grey in colour but are either dominated or have patches varying in shades of dark brown, red and in the case of the example from 08/02/10 (1) some orangey-brown also. None of the fragments or cakes appear to be crystallised being dull coloured. The fragments and cakes from locations 19/02/10 (5) and 26/02/10 (8) have magnetic areas suggesting that some parts have metallic iron content. The cake from 08/02/10 (1) has a heavily magnetic lump approximately 50mm in length and 20mm thick on its top surface. This lumps has some dark red and orangey brown patches which may be oxidisation of areas with more metallic iron content.

All the slags in this type vary considerably in morphology. The top surface of the slag cake from 08/02/10 (9) is rough with some small rounded protrusions but mainly dominated by angular and sharp protrusions of material. These angular projections appear to have been formed by the numerous charcoal impressions which dominate the surface. These impressions are <20mm in size. The surface seems pretty solid with the exception of the few small areas where the slag has fractured revealing some spherical porosity. The top surfaces of the examples from 13/02/10 (13) and 26/02/10 (8) are broken leaving small sharp protrusions of material. The surfaces are rough and show some porosity in the form of small spherical and globular voids. On the edges of the surfaces there appears to be remains of a smoother, solid and more molten crust. It is not unreasonable to suggest that the entirety of the top surfaces may once have been covered by this crust which probably broke off after deposition. Charcoal impressions up to 28mm in size are present on the example from 26/02/10 (8) which adds to the roughness of the surface. The top surface of the cake from 08/02/10 (1) is dominated by smoother rounded flow slag projections. It is medium rough in texture with few very small to small sharp protrusions that rise from the more rounded slag surface. It is reasonably solid with few spherical and globular voids apparent in the small areas that have broken. On one side a small rounded lump protrudes from the surface about 20mm. This lump as mentioned above is magnetic and must contain some metallic iron. The top surfaces of the fragments from 19/02/10 (5) are more even with no major protrusions. They are mid rough to coarse sandpaper rough in texture with many very small sharp protrusions. They are solid but there are a few spherical voids apparent in areas where the top surface crust has chipped off.

The bottom surfaces also vary slightly between the different slag cakes of this type. All bases are curved (convex) but do vary in texture. The cake from 08/02/10 (9) is rough with many small sharp protrusions created by the small charcoal impressions <10mm in size which dominate the surface. The surface is solid except for very small spherical voids apparent where some protrusions have broken. The bottom surfaces of the fragments and cakes from 13/02/10 (13) and 26/02/10 (8) are uneven and medium rough to coarse sandpaper rough in texture. They are undulated but have small imprints (not diagnostic but probably small stones) creating very small sharp protrusions. Some small quartz and stone inclusions <4mm in size are still adhering to the base of these cakes. The bases are uneven and not perfectly convex but have some large rounded protrusions and dips suggesting that the base of the furnace was not even. The cake from 08/02/10 (1) has a broken base. It is very even with no major protrusions and is covered in dark grey reduced/vitrified coarse clay. The broken nature of this clay layer with its small quartz inclusions (<4mm) gives the base a medium to very coarse sandpaper texture. It is also semi-porous with many randomly spread small spherical and globular voids. The two small fragments from 19/02/10 (5) have medium sandpaper rough bases dominated by very small charcoal impressions (<6mm). The bases are rounded and very even, similar to some of the larger type 1 and 1.1 cakes described above.

The broken edges on the fragments and cakes of this type enable cross sections through the main bulk of the slags to be seen. Most examples appear to be solid to semi-porous with randomly positioned spherical, globular and few irregular voids <12mm in size. The exception is the cake from 08/02/10 (9) which is very porous in nature. The whole cake is dominated by angular charcoal impressions/voids and where the slag has broken many small spherical and globular voids <5mm in size are apparent.

08/02/10 (9)

13/02/10 (13)

19/02/10 (5)

26/02/10 (8)

08/02/10 (1)

Appendix C.2.6 – FS1.5

Characteristic features	Very small plano-convex cakes, most complete, clear slag layering
Size range	From the smallest nearly complete cake 115mm in length, 100mm in width and 75mm in thickness to the largest complete cake 143mm in length, 113mm in width and 63mm in thickness. Some small broken fragments were also recovered <93mm in maximum length.
Locations in which found	02/02/10 (8)

There are very few type 1.5 furnace slag fragments and cakes. They are very different to any other furnace slags recovered. Their major characteristic features are that they are very small plano-convex cakes, most are complete and look to have been made by the accumulation of individual runs of slag (slag layering). They occur only in location 02/02/10 (8). The six complete or almost complete fragments range in size from the smallest cake 115mm in length, 100mm in width and 75mm in thickness to the largest complete cake 143mm in length, 113mm in width and 63mm in thickness. Some of the cakes are up to 105mm thick. Three small broken fragments were also recovered <93mm in maximum length. Although most of their edges are broken they retain enough of their original top or bottom surfaces to be identified as this slag type. The type 1.5 slag cakes are plano-convex in profile (deep bowl shaped) and circular or oval in plan. Some of the cakes appear to have a slight dip on the top surface making them almost concave (concavo-convex). The diameters are not perfectly circular but point to an inner furnace diameter of around 130mm. It may be interesting to point out that the widest one is also the shortest in terms of height.

The slags themselves are dark greyish-blue in colour but are coated in a dark sandy brown colour. Some also have a significant proportion of brownish-yellowy-orange and brownish-red patches on the top surface. If indeed these remains are the result of the bloomery process it is possible that the coloured patches are oxidisation of more metallic parts which may have been in contact with the bloom. However, none of the cakes or fragments are magnetic.

All the cakes are similar in morphology but the top surfaces do vary slightly in texture. Some have smoother areas of well molten rounded slag with small rounded protrusions but the majority are more agitated and rough to the touch with very small to small sharp protrusions of material. Even the more molten rounded areas are mostly medium to rough sandpaper rough in texture as they are covered with very small sharp protrusions. The presence of charcoal impressions cannot be ascertained as most of the slags appear to have had a high surface tension. However, it is reasonable to assume that the small (sometimes angular) depressions in between the surface protrusions found on the more agitated examples were indeed created by small charcoal lumps (probably 15mm in size).

Their undersides are very interesting. They are convex but due to their small diameter and relatively large thickness the base curvatures rise sharply on the sides until they make contact with the flat or concave top surface (like a deep bowl shape). These steep sides and bases reveal that the slags were made of a consolidation of small runs of slag that have fused together at the bottom of the furnace or hearth. Clear horizontal (parallel to top surface) layers of slag are visible on most examples suggesting that either small dribbles or runs of slags accumulated on top of each other or that the process initiated several meltings of slag whereby previous layers of slag ran to the base of the furnace (pooled) and partially solidified before the next layer of slag could accumulate on top. Since these slag layers are not very even it is more likely that the slag consolidated from individual dribbles or runs of slag. These bases are mostly undulated and smooth to mid rough in texture. Some bases also have a few small stone inclusions (<3mm) still imbedded in the undulations. One example as a large area of almost perfectly smooth slag in the centre of its underside suggesting that the slag was more molten or less viscous in this area. The tallest fragment is a bit rougher than the others with its whole underside a coarse sandpaper texture dominated by many very small pits and protrusions. In some of those pits there are some small stones. The majority of these cakes also have a considerable amount of charcoal or organic material impressions on their undersides. Most are very thin (2-3mm) and up to 30mm in length.

The complete cakes appear to be solid in nature with very few voids apparent on the surfaces but those with broken edges reveal that most are semi-porous with some spherical and globular voids <6mm in size. One of the largest cake is broken on one side revealing a large elongated void in its centre around 40mm in length.

02/02/10 (8)


FURNACE
5cm
02/02/10
8


FURNACE
5cm
02/02/10
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FURNACE
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FURNACE
5cm
02/02/10
8


5cm

Appendix C.2.7 – FS1.6

Characteristic features	Large plano-convex cake, bucket shaped.
Size range	One cake approximately 211mm in diameter and 210mm in thickness (height).
Locations in which found	26/02/10 (5/6)

Type 1.6 furnace slag constitutes of one unique plano-convex slag cake of unusual shape found in location 26/02/10 (5/6). It is a complete cake whose shape resembles that of a bucket. It is circular in plan with a flat top and flat sides that leave the top at almost a 90 degree angle and then taper slightly towards a rounded bottom. It is 211mm in diameter at the top, around 150mm at the base and 210mm in thickness/height. The slag is dark greyish-blue in colour but the top surface is dominated by dark grey with some areas of dark reddish-brown. The cake is not magnetic.

The top surface is very rough and mainly consists of small to medium protrusions of slag. These protrusions seem to have been created by charcoal lumps; in between the sharp projections are many charcoal impressions and angular voids 19-20mm in size. The majority of the material projections are broken revealing some spherical and globular porosity up to 10mm (mainly <5mm) in size. These add to the rough texture of the surface. In other parts where there are small breaks, very small spherical voids <2mm are present. Due to the mostly complete nature of the cake it is hard to estimate how porous it is inside but as a whole it appears to be solid to low in porosity with no major void concentrations on the base.

The underside and sides of the cake are very interesting as they show well-formed rounded slag flows that have ran and stuck to each other forming a layered cake of horizontal greyish-blue flow slag. The slag appears to me made of the amalgamation of small flows of slag that have consolidated at the base of the furnace or hearth. Most of these layers of slag are between 10-20mm thick. The exterior surface is undulated (similar to tap slag) and in some cases small stones are still imbedded in these undulations. In some parts of the cake but especially on one side there is a thin adhering layer of mid to dark grey reduced coarse clay. This clay has many medium sized quartz crystals up to 7mm. This suggests that the cake formed against the furnace wall and that the base of the furnace may have been lined with clay (although there is no clay adhering to the curved underside). In a few areas but especially near the top of the cake there are a few angular charcoal impressions/voids. It is also worth noting that the top 50-100mm of the cake seems to be more consolidated as these layered slag runs are either no longer visible or faint. This suggests that the process may have been running its optimum towards the end producing less viscous slag. Another possibility is that the slag had to travel a lower distance to pool leaving less time for it to cool. The actual underside is slightly curved and shows more of these slag runs overlapping one another. Like the side of the cake there are also a few medium to large angular charcoal impressions. It has the same undulations as the sides and in some areas there are medium sized quartz inclusions adhering to these. Of importance is the presence of thin and long organic impressions approximately 2mm wide and up to 20mm in length. Overall, this cake shares many morphological similarities with the type 1.5 furnace slag cakes discussed above.


26/02/10 (5/6)

Appendix C.2.8 – FS2

Characteristic features	All broken edges, dominated by charcoal impressions and voids, very rough surfaces, porous to very porous
Size range	From the smallest fragment 33mm in maximum length to the largest 196mm in length, 125mm in width and 73mm in thickness
Locations in which found	29/01/10 (2), 01/02/10 (1), 02/02/10 (1) (4) (6), 03/02/10 (3) (15), 05/02/10 (1) (2) (6), 06/02/10 (4), 08/02/10 (10), 09/02/10 (6), 10/02/10 (2), 11/02/10 (1) (5), 12/02/10 (1), 16/02/10 (6), 17/02/10 (4), 18/02/10 (2) (3), 19/02/10 (3), 21/02/10 (3), 22/02/10 (1), 25/02/10 (4), 26/02/10 (1)

Type 2 furnaces slags were recovered in many locations. Their main characteristic features are their fully fragmentary amorphous nature with all edges broken and the fact that these surfaces are dominated by charcoal voids and impressions giving them a very rough and porous texture. Type 2 furnace slags were recovered from locations 29/01/10 (2), 01/02/10 (1), 02/02/10 (1) (4) (6), 03/02/10 (3) (15), 05/02/10 (1) (2) (6), 06/02/10 (4), 08/02/10 (10), 09/02/10 (6), 10/02/10 (2), 11/02/10 (1) (5), 12/02/10 (1), 16/02/10 (6), 17/02/10 (4), 18/02/10 (2) (3), 19/02/10 (3), 21/02/10 (3), 22/02/10 (1), 25/02/10 (4) and 26/02/10 (1).

All type 2 furnace slags are broken with the majority of their original surfaces missing. There are a few exceptions which will be described at the end of this section. It is hard to estimate the original size of these slags due to their fragmentary and amorphous nature. The fragments range in size from the smallest fragment 33mm in maximum length to the largest 196mm in length, 125mm in width and 73mm in thickness. They are likely slag that solidified in the centre of the furnaces around the charcoal charge explaining their porous and charcoal void dominated surfaces.

All examples are dark grey in colour but all have patches varying in shades of dark brown, dark red and dark orange. None are crystallised with all examples being dull in colour. The majority of type 2 furnace slags are light and are not magnetic. The exceptions are found in locations 02/02/10 (4) (6), 03/02/10 (3), 05/02/10 (2), 18/02/10 (2), 19/02/10 (3), 22/02/10 (1) and 26/02/10 (1) which have some magnetic areas. This suggests that these fragments have some metallic iron content. It is also worth noting that the magnetic areas tend to correlate with some of the darker brownish-reddish-orange coloured patches which may be oxidisation.

Since the majority of the type 2 furnace slags are fragmentary they do not have clear top or bottom surfaces. They are amorphous in shape and dominated by broken surfaces. These surfaces are rough to very rough in texture with sharp angular small to medium projections created by the breaks. In addition all fragments are dominated by medium to large charcoal voids and impressions up to 75mm but mostly <30mm in size. These angular voids add to the rough texture of the broken surfaces. In some cases small remains of charcoal are still adhering to the insides of these voids. There also appears to be concentrations of dark brownish-red or orange in the voids with thin flaking layers of slag. Some fragments have unbroken projections which appear to be either rounded like tendrils or sharp and angular. In some instances small areas of more molten slag remain. These are usually thin crusts of rounded uneven slag which must be the remains of the original surfaces. The majority of the protrusions created by these large charcoal voids are broken revealing the slags to be porous to very porous in nature. The majority of these voids are spherical or globular up to 10mm but mostly <8mm in size. Some fragments also have irregular voids up to 12mm in size. The porous nature of these slags means that they are all light in density.


29/01/10 (2)


02/02/10 (4)


08/02/10 (1)

08/02/10 (10)


09/02/10 (6)


10/02/10 (2)

11/02/10 (1)

16/02/10 (6)

18/02/10 (3)

26/02/10 (1)


26/02/10 (1)

Of special interest are the fragments recovered from 02/02/10 (1), 12/02/10 (1) and 27/02/10 (2). The rest of the surfaces are similar to the others described above but all three fragments have one flat edge suggesting that they solidified against a hard surface. The fragment from 02/02/10 (1) has a very flat but slightly curved surface with a coarse sandpaper texture and flattened protrusions. The fragments from 12/02/10 (1) and 27/02/10 (2) on the other hand are rougher with very small rounded sometimes sharp protrusions of material. In some areas these protrusions are rounded prills of slag that appear to have shaped around very small charcoal impressions (<5mm). It is possible that these solidified at the base or side of the furnace.

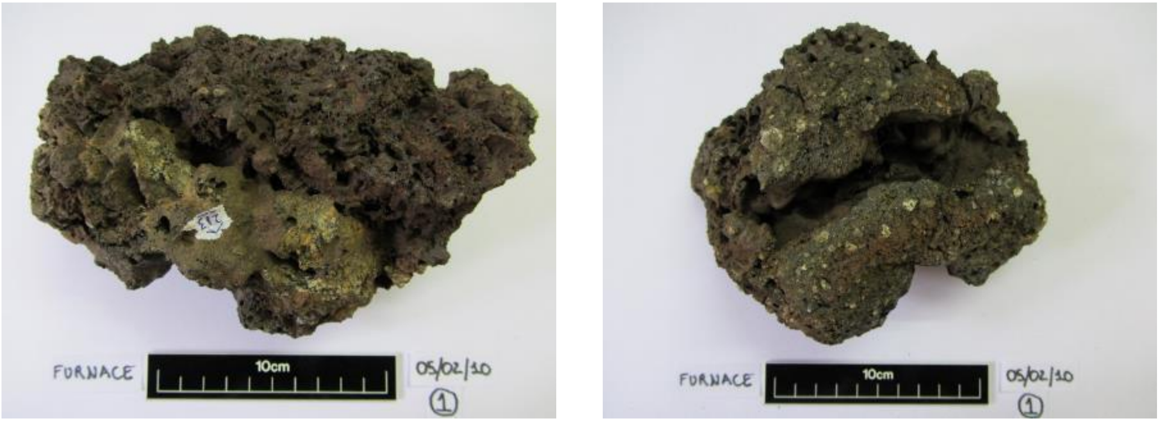

02/02/10 (1)

12/02/10 (1)

27/02/10 (2)

Three other examples from locations 03/02/10 (3), 05/02/10 (1) and 18/02/10 (2) have adhering clay on one edge. This suggests that they solidified against the furnace walls. The rest of the surfaces are the same as all others in this furnace slag type. The surfaces with adhering clay appear to be slightly curved (convex) suggesting that these fragments partially solidified against the furnace wall. The clay on the fragments from 03/02/10 (3) and 05/02/10 (1) is coarse with many quartz crystals up to 9mm but mostly <5mm in size. The clay on the fragment from 18/02/10 (2) is medium coarse with fewer quartz up to 12mm but mostly <3mm in size. Both fragments from 05/02/10 (1) and 18/02/10 (2) contain a significant proportion of vitrified clay where the slag has reacted with the melting wall. The vitrification is dark grey with many un-melted white quartz crystals speckling the surface. The fragment from 18/02/10 (2) also has a rounded depression about 40mm wide in the vitrification which appears to have been where the nozzle end of tuyere was located causing greater melting of the furnace wall in this area.

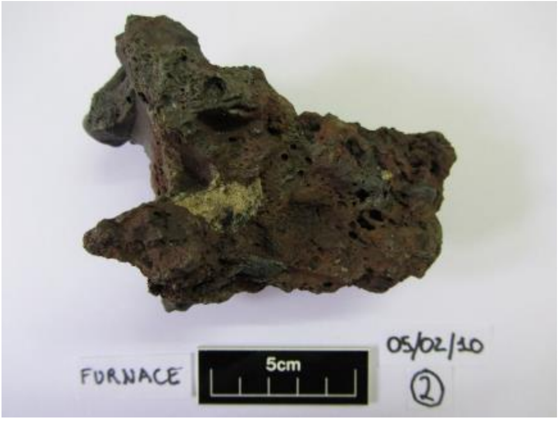
03/02/10 (3)



05/02/10 (1)

18/02/10 (2)

Two more fragments have special morphological characteristics which deserve mention. These were found in locations 05/02/10 (2) and 25/02/10 (4). Their top surfaces are similar to all other fragments from this type dominated by large charcoal voids but their undersides are undulated like that of tap slag. The undulations are smooth and rounded and the surfaces reasonably flat suggesting that this may have been tapped slag perhaps at the start of the flow where significant charcoal rich furnace slag spilled out of the furnace.



05/02/10 (2)

25/02/10 (4)

Appendix C.2.9 – FS2.1

Characteristic features	Amorphous more complete lumps, tendril flow slag, dominated by charcoal voids and impressions
Size range	From the smallest fragments <10mm in maximum length to the largest lump 206mm in length, 128mm in width and 96mm in thickness.
Locations in which found	25/01/10 (6), 28/01/10 (1), 29/01/10 (1), 02/02/10 (7), 03/02/10 (3) (6) (9), 06/02/10 (2), 08/02/10 (1) (2) (3) (4) (9), 09/02/10 (1), 10/02/10 (1), 16/02/10 (2) (6), 18/02/10 (1) (2) (4) (5), 19/02/10 (3) (4) (5), 21/02/10 (9), 22/02/10 (3) (4), 23/02/10 (2), 24/02/10 (3), 26/02/10 (1) (3) (6) (7), 27/02/10 (4) (7)

Type 2.1 slags are one of the most abundant furnace slag sub-types in the assemblage. They are similar to the type 2 furnace slags but more complete amorphous lumps, are dominated by rounded slag tendril protrusions and large charcoal voids/impressions. Slags of this type have been found in locations 25/01/10 (6), 28/01/10 (1), 29/01/10 (1), 02/02/10 (7), 03/02/10 (3) (6) (9), 06/02/10 (2), 08/02/10 (1) (2) (3) (4) (9), 09/02/10 (1), 10/02/10 (1), 16/02/10 (2) (6), 18/02/10 (1) (2) (4) (5), 19/02/10 (3) (4) (5), 21/02/10 (9), 22/02/10 (3) (4), 23/02/10 (2), 24/02/10 (3), 26/02/10 (1) (3) (6) (7) and 27/02/10 (4) (7).

Most of the type 2.1 slag lumps have some small surface fractures with broken projections but the majority appear to be almost complete. They range in size from the smallest fragments <10mm in maximum length to the largest lump 206mm in length, 128mm in width and 96mm in thickness.

All the type 2.1 furnace slags are dark grey in colour but all also have different coloured patches varying in shades of dark brown, red, purple and orange. None of the slags appear to be crystallised, all being dull coloured and homogenous in section. Most lumps are not magnetic but some of the examples found in locations 03/02/10 (3) (9), 08/02/10 (1) (9), 10/02/10 (1), 16/02/10 (2), 18/02/10 (1) (2) (4) (5), 19/02/10 (4) (5), 22/02/10 (3) and 23/02/10 (2) have magnetic patches suggesting metallic iron content in some areas. None are fully magnetic. Two examples from locations 09/02/10 (1) and 19/02/10 (5) differ slightly in colouration from the others. They are dominated by a greyish white to light grey colouration. They are also less dense than the other slag lumps. The example from 19/02/10 (5) has remains of vitrified clay and it is possible that a significant proportion of the slag is clay material which might explain the colouration. They could also be slags with an elevated proportion of charcoal ash or in the case of the lump from 09/02/10 (1) the colouration may be indicative of the addition of a flux.

09/02/10 (1)

19/02/10 (5)

Slags of this type are amorphous in shape without any clear definition of top and bottom surfaces. All examples have a similar morphology. They closely resemble the type 2 furnace slags but appear to be more complete with more natural edges remaining. Their external surfaces are dominated by small to medium rounded tendril like protrusions. These many protrusions give the slags a medium to rough texture and in the broken areas they are very rough to the touch with more angular and sharp protrusions. In between these rounded slag projections are large charcoal voids and impressions up to 45mm but mainly <30mm in size. These angular voids add to the rough nature of the surfaces. In some cases small remains of charcoal line these voids. Some lumps have more bulbous surfaces with larger rounded protrusions or flows. Some examples also have small areas with flatter crusts usually covered in very small sharp protrusions making them coarse sandpaper textured. Many of the dark brownish-orange patches are gritty in texture. These slags look like the amalgamation of smaller slag tendrils which have consolidated around charcoal fragments. Since the majority are almost complete it suggests that they solidified isolated from the main slag bulk in the furnaces.

Due to the large charcoal voids the majority of the slags are porous to very porous. The breaks also reveal many small spherical and globular voids within the slag up to 30mm but mainly <10mm in size. Some examples almost have a honeycomb texture to them with only thin layers of slag in between the large quantity of gas voids.

03/02/10 (3)

03/02/10 (6)


08/02/10 (3)

16/02/10 (2)


16/02/10 (6)


18/02/10 (1)


18/02/10 (2)


18/02/10 (4)

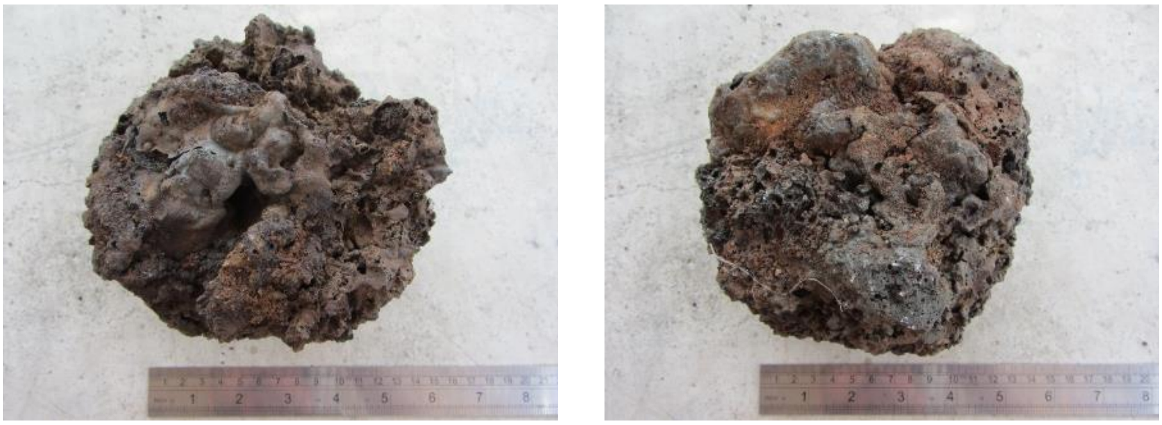

21/02/10 (9)


22/02/10 (3)

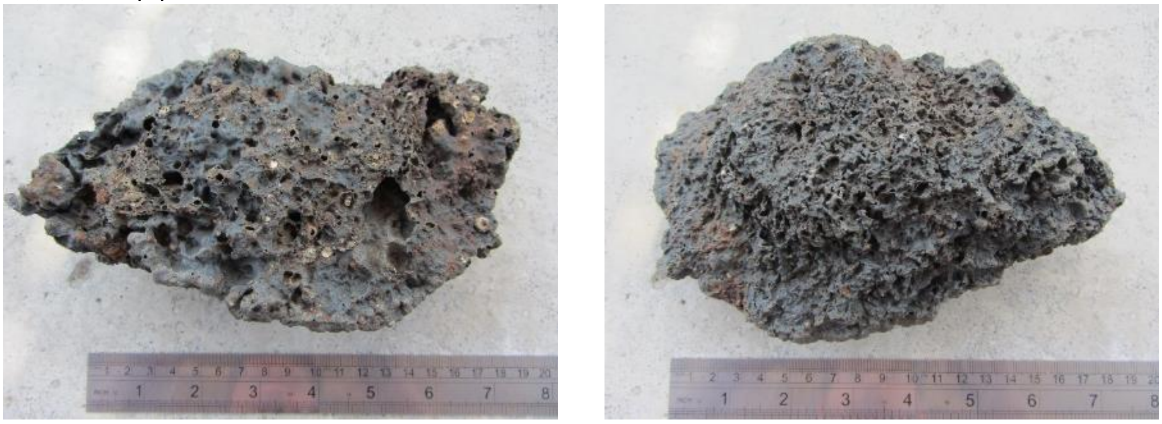
26/02/10 (7)

25/01/10 (6)

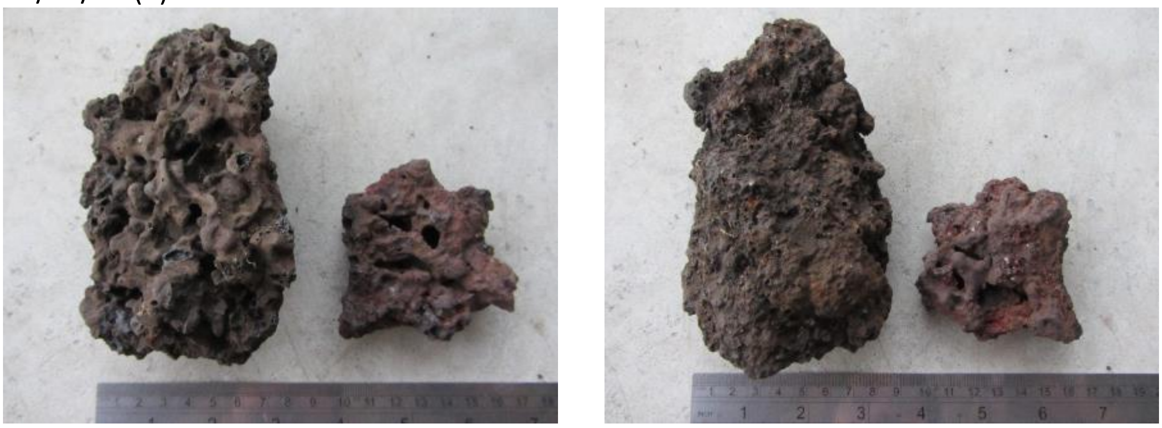
Of special interest are the lumps in locations 02/02/10 (7), 06/02/10 (2), 08/02/10 (9), 18/02/10 (4), 19/02/10 (3) (4) (5), 24/02/10 (3) and 26/02/10 (3). These have one side that differs from the rest of their surface. They have smaller rounded prill-like protrusions with the gaps in between dominated by small charcoal impressions <10mm in size (almost like large and deep undulations). These less agitated sides are all shaped being either flatter or curved (convex) suggesting that they may have been in contact with harder surfaces or compacted charcoal fines. The surfaces are still medium to rough depending on the rounded nature of the protrusions. Some of these are sharper and more angular than others.



02/02/10 (7)

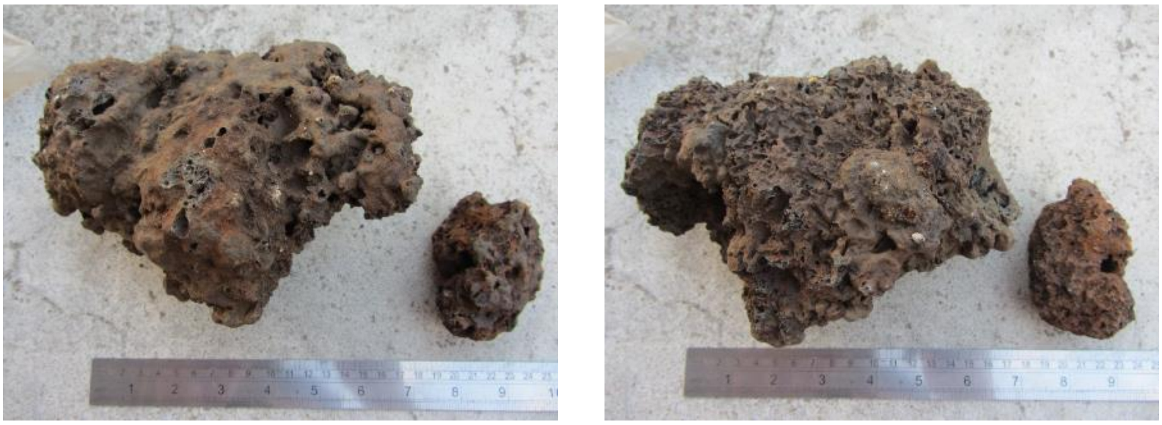


06/02/10 (2)



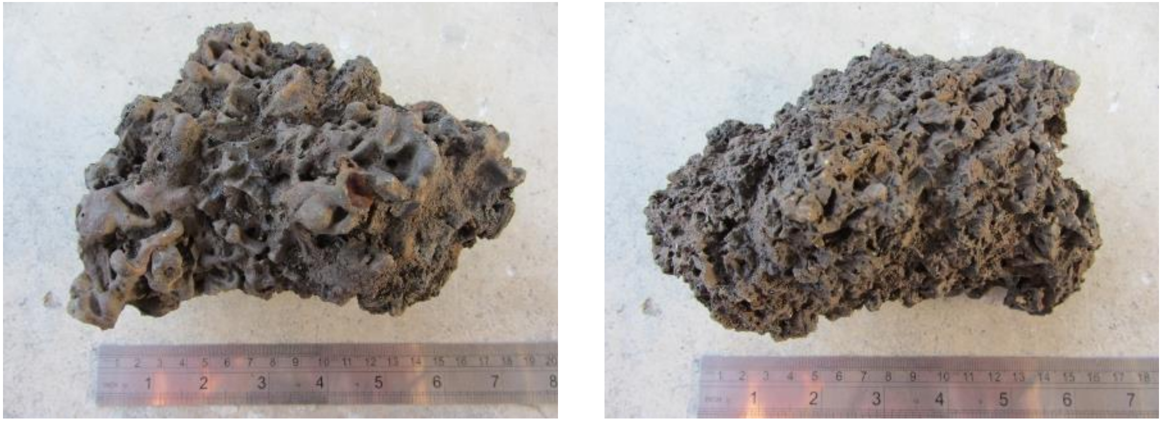
08/02/10 (9)

18/02/10 (4)



19/02/10 (3)

10/02/10 (4)



24/02/10 (3)

Two type 2.1 slag lumps deserve special mention. The first is the example from 03/02/10 (9). It is curved (convex) on one side with remains of dark grey reduced and vitrified clay. This clay is coarse in fabric dominated by quartz crystals mostly <5mm in size. The clay and slag have fused suggesting that the slag solidified against the furnace wall.



03/02/10 (9)

The other lump is found in location 26/02/10 (6). It is 122mm in length, 274mm wide and 133mm in height and has a large tuyere fragment adhering to one side. The slag is very rough and agitated and broken on most sides. It is slag that has solidified around the charcoal charge as large charcoal angular impressions dominate the cake. Most are <30mm but there are some larger impressions up to 40mm which are quite cuboid in nature. The slag on the many fractures is dark grey in colour but the majority of the surfaces are a dark reddish brown. The fractures show many tiny spherical voids mainly <3mm. The vitrification at the nozzle end melting into the slag is a mixture of light to mid grey with a mid brown tinge. Some parts of the underside have medium sized rounded projections. On the underside there are parts of the slag that are flattened and coarse sandpaper rough suggesting that they had some sort of contact with the base of the furnace. On the rim end of the tuyere the slag is also flattened suggesting that it solidified against the furnace wall. The tuyere looks to have been protruding at least 165mm into the furnace.

The tuyere on the top is broken but approximately 1/2 to a 1/3 of its original circumference remains. The rim end is missing and the nozzle appears to have been heavily molten (built in usual way). As it stands the tuyere is 170mm in length, the internal diameter towards the rim end is 62mm and 48mm at the nozzle end. The wall thickness varies from 19-24mm and it appears to be made of a mid coarse fabric with small quartz inclusions (<3mm). The majority of the clay is dark grey reduced but there is a hint of dark orangey grey towards the rim end. The nozzle is molten and deformed slightly. There is no sign of a flaring rim and it must have been almost a tubular shape with a slight tapering towards the nozzle. The slag appears to come almost through the tuyere at the rim end and it is possible that this it broke during firing. It could also have just been added to the furnace as flux but very unlikely. There are small remains of what appears to be furnace wall or another tuyere on one side made of the same fabric.



26/02/10 (6)

It is also worth mentioning that the lumps from 25/01/10 (6) represent the majority of the slag recovered at the location. The sheer quantity of this slag type at this location suggests a different smelting technology than what is seen at other sites. The slag lumps found are similar to those described above but appear more molten with more tightly packed rounded flow slag. There are less charcoal voids and more charcoal impressions. In addition, many of the larger lumps have shaped (flattened) edges. These differ from those described above because the flattened sides are smoother with none of the characteristic small charcoal impressions seen on the others. They also appear to be more porous with an almost honeycomb texture to them. The broken edges are dominated by spherical and globular voids <12mm in size and a few elongated ones <30mm in size. One of the lumps also appears to have a hammerscale flake stuck to its surface. This flake is approximately 20mm in length and suggests that smithing was occurring at the same location.


25/01/10 (6)

25/01/10 (6)

25/01/10 (6)

Appendix C.2.10 – FS3

Characteristic features	Small solid to semi-porous amorphous lumps, almost complete
Size range	From the smallest fragments <40mm in maximum length to the largest lump 199mm in length, 159mm in width and 118mm in thickness
Locations in which found	26/01/10 (7) (8), 28/01/10 (2), 29/01/10 (5), 01/02/10 (1) (2), 02/02/10 (6), 03/02/10 (1) (13), 06/02/10 (2), 08/02/10 (9), 12/02/10 (1) (3) (5) (6) (7) (10), 13/02/10 (8), 17/02/10 (1) (4) (6), 18/02/10 (1), 19/02/10 (3) (5), 21/02/10 (1) (2), 22/02/10 (3), 23/02/10 (8), 24/02/10 (2), 25/02/10 (1) (5), 26/02/10 (1) (7)

Many type 3 furnace slags were collected. Their main characteristic features are their generally small size, complete or almost complete nature and the fact that most are solid to semi-porous. Slags of this type were found in locations 26/01/10 (7) (8), 28/01/10 (2), 29/01/10 (5), 01/02/10 (1) (2), 02/02/10 (6), 03/02/10 (1) (13), 06/02/10 (2), 08/02/10 (9), 12/02/10 (1) (3) (5) (6) (7) (10), 13/02/10 (8), 17/02/10 (1) (4) (6), 18/02/10 (1), 19/02/10 (3) (5), 21/02/10 (1) (2), 22/02/10 (3), 23/02/10 (8), 24/02/10 (2), 25/02/10 (1) (5) and 26/02/10 (1) (7).

The majority of the type 3 cakes are complete or almost complete with only small breaks on their edges. A few fragments are more broken making it hard to estimate their original size. Most are amorphous in shape without clearly defined top or bottom surfaces. They range in size from the smallest fragments <40mm in maximum length to the largest lump 199mm in length, 159mm in width and 118mm in thickness.

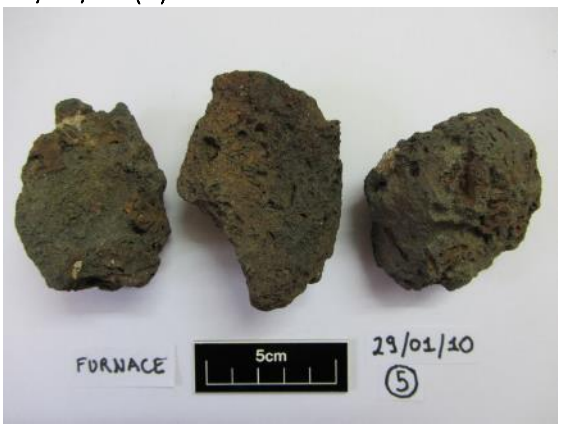
All examples are dark grey in colour with many different coloured patches varying in shades of dark brown, red, purple and orange. Some also have light to mid grey coloured patches. The lumps in 12/02/10 (3) (6) and (7) are dark greyish-purple in colour. None of the fragments are crystallised, all being dull in colour. Some lumps in locations 01/02/10 (2), 03/02/10 (13), 06/02/10 (2), 08/02/10 (9), 12/02/10 (1) (5) (6) (10), 17/02/10 (1), 19/02/10 (5), 21/02/10 (1) (2), 23/02/10 (8), 25/02/10 (1) (5) and 26/02/10 (1) (7) are magnetic in parts suggesting metallic iron content in those areas. The example in location 08/02/10 (9) is magnetic over most of its surface area suggesting that it contains a large quantity of metallic iron. On most lumps the magnetic areas are associated with dark brownish-orange or red patches which may be corrosion of these iron rich parts.

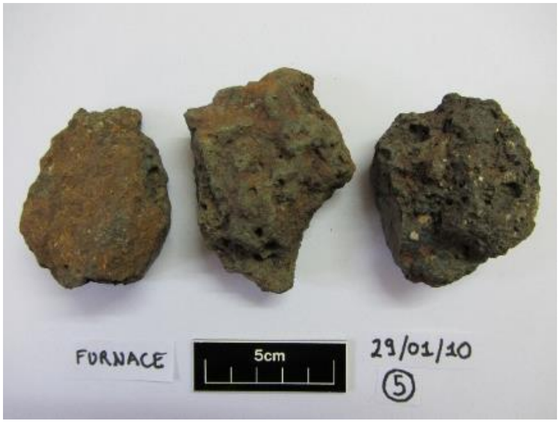
Since the majority are amorphous in shape they do not have diagnostic top and bottom surfaces. Most have a homogenous surface texture covering their entire surface area. On some sides the lumps appear to have made contact with a harder surface as most appear to be shaped; either flattened or slightly convex. Most surfaces are medium rough in texture with only small protrusions of material. In some examples these protrusions are more rounded while on others they are sharper and more angular making the surfaces rougher to the touch. Many also have large gritty dark brownish-orange patches with many very small protrusions giving these areas a coarse sandpaper texture. The majority of the intact surfaces are solid to low in porosity with no to very few small spherical voids apparent. Most examples also have shallow charcoal impressions visible on their surfaces. These are up to 33mm in size but mostly <20mm. The exceptions where no charcoal impressions are visible are found in locations 03/02/10 (13), 12/02/10 (1), 17/02/10 (4), 18/02/10 (1), 21/02/10 (2), 22/02/10 (3), 23/02/10 (8) and 26/02/10 (1) (7). The shaped sides are either medium rough and similar to the rest of the surfaces but with smaller almost imprint-like projections or are smooth to coarse sandpaper textured being undulated with small rounded dips like in the lumps from 03/02/10 (1) (13), 06/02/10 (2), 12/02/10 (6) and 24/02/10 (2). Two lumps found in locations 26/01/10 (8) and 12/02/10 (3) also have medium rough shaped sides dominated by very small sharp protrusions and dominated by charcoal impressions <12mm in size. It is possible that these solidified against compacted charcoal fines.

The main defining characteristic of this type are their reasonably solid nature. Most lumps are solid to semi-porous with randomly spread spherical and globular voids up to 18mm but mostly <10mm in size. Some examples in 26/01/10 (8) and 12/02/10 (3) have very few elongated or flattened voids up to 19mm in length. The main exceptions are found in locations 08/02/10 (9), 12/02/10 (6) (7) and 17/02/10 (1) where some slags are porous in parts.


26/01/10 (7)


26/01/10 (8)



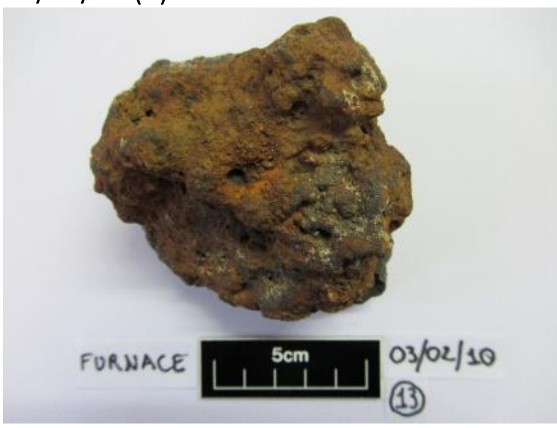


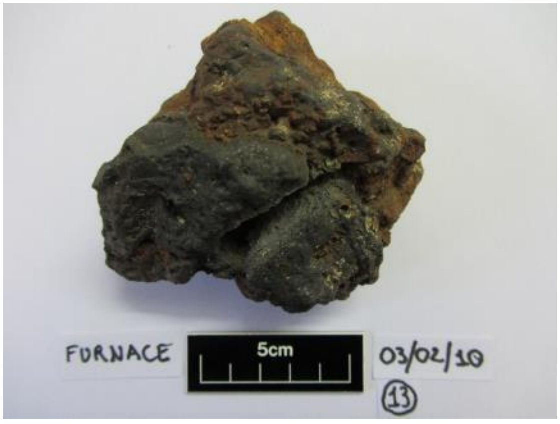
29/01/10 (5)


01/02/10 (1)

01/02/10 (2)

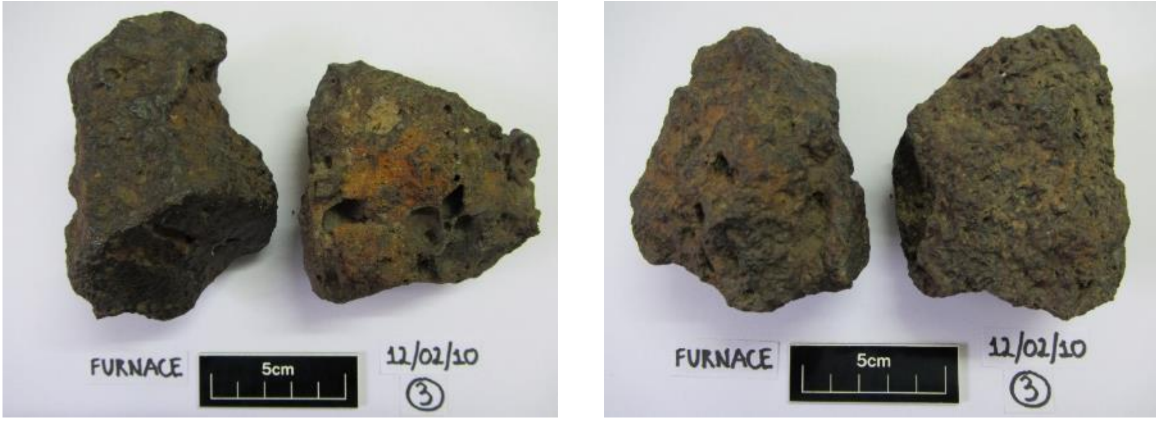
03/02/10 (1)





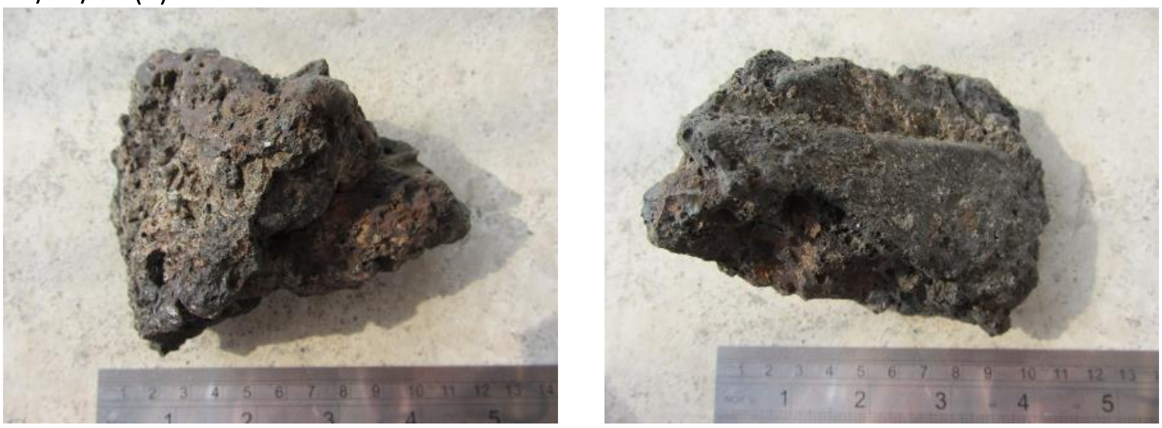
03/02/10 (13)

06/02/10 (2)



12/02/10 (3)


12/02/10 (5)


12/02/10 (6)


12/02/10 (10)

17/02/10 (1)

17/02/10 (6)


19/02/10 (5)


24/02/10 (2)


25/02/10 (5)


26/02/10 (7)


19/02/10 (3)

Appendix C.2.11 – FS4

Characteristic features	Amorphous small lumps, rough to very rough uneven surfaces
Size range	From the smallest fragment 30mm in maximum length to the largest lump 111mm in length, 95mm in width and 43mm in thickness
Locations in which found	01/02/10 (4) (5), 03/02/10 (15), 06/02/10 (2), 09/02/10 (7), 12/02/10 (1) A8 (6) (8), 15/02/10 (3), 17/02/10 (3), 26/02/10 (3) (8)

Very few type 4 furnace slag lumps were recovered. Their main characteristic features are that they are small amorphous lumps and rough to very rough in texture with uneven surfaces. Slags of this type were found in locations 01/02/10 (4) (5), 03/02/10 (15), 06/02/10 (2), 09/02/10 (7), 12/02/10 (1) A8 (6) (8), 15/02/10 (3), 17/02/10 (3) and 26/02/10 (3) (8).

Most of the type 4 furnace slags have some broken edges but these appear to be small suggesting that the majority are almost complete. However, some of the smaller fragments in locations 01/02/10 (4), 12/02/10 (6) and 15/02/10 (3) are more fragmentary with broken edges on most sides. Some also just have a thin layer of surface slag (crust) which appears to have chipped off in parts. They range in size from the smallest fragment 30mm in maximum length to the largest lump 111mm in length, 95mm in width and 43mm in thickness.

Most examples are dark grey in colour with many coloured patches varying in shades of dark brown, red, purple, yellow and orange. Some of the lumps from 01/02/10 (4) are black in colour while the one in 09/02/10 (7) is dark purplish grey. None of the type 4 slag lumps are crystallised being primarily dull coloured but the fragments from 03/02/10 (15) and 26/02/10 (8) have shiny fractures. The examples from 03/02/10 (15), 06/02/10 (2), 12/02/10 (8), 15/02/10 (3), 17/02/10 (3) and 26/02/10 (3) have magnetic areas suggesting that they contain metallic iron in some parts. These magnetic areas appear to correlate with darker brownish-purplish-red patches on the surfaces. This colouration may therefore be oxidisation of the more iron rich areas.

Since all type 4 furnace slags are amorphous in shape they do not have clear top or bottom surfaces. Most have similar surface morphologies on all sides. The majority are rough to very rough in texture with small to medium projections of material dominating. This gives them very angular and uneven appearances. In addition to these larger protrusions the surfaces are usually covered by many very small projections of material making parts coarse sandpaper textured. Most also have charcoal impressions up to 25mm in size but mostly <15mm. These add to their rough texturing. In some cases like one of the lumps from 06/02/10 (2) small charcoal remains still line the impressions. Some lumps have more rounded projections on their edges suggesting that they were well molten but these are still covered by very small sharp protrusions. The surfaces range between solid and porous depending on the preservation of the natural surfaces. On some the top slag layer or crust has chipped off revealing greater porosity underneath.

The small breaks on the lumps and fragments reveal a good cross-section. The majority are porous to very porous in nature dominated by small spherical and globular voids <10mm but mostly <5mm in size. Some examples display an almost honeycomb textured appearance with voids dominating and thin layers of slag in between. The only exceptions are those found in locations 03/02/10 (15) and 15/02/10 (3) which are semi-porous with fewer spherical and globular voids present on the surfaces and broken edges.

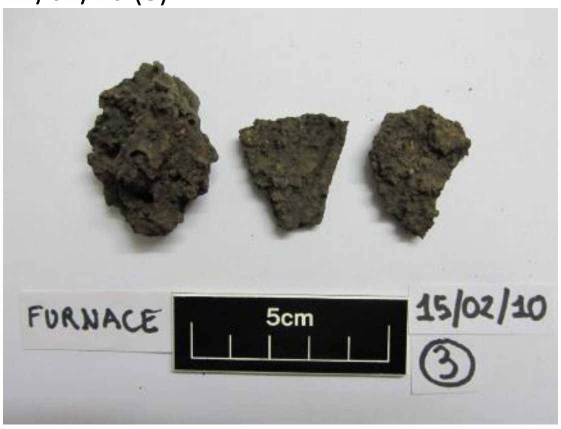

01/02/10 (4)

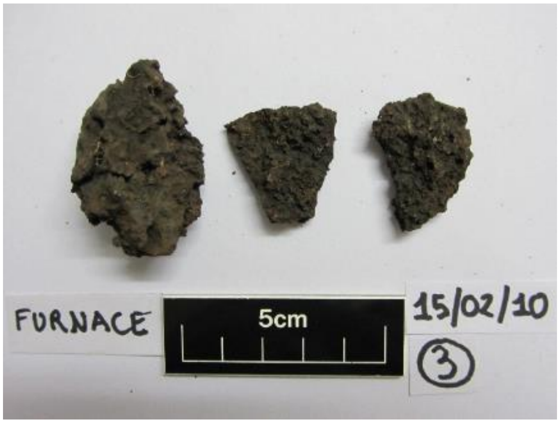
03/02/10 (15)

06/02/10 (2)

09/02/10 (7)

12/02/10 (8)





15/02/10 (3)


17/02/10 (3)

26/02/10 (3)

26/02/10 (8)

Of special interest is the lump from 01/02/10 (5). It has a few small surface fractures but appears to be almost whole. It also has a similar rough to very rough surface texture than the other slags in this type with small sharp protrusions of material and an uneven surface. The main interesting feature is that it has one shaped (slightly convex) side with adhering mid grey reduced clay. This clay is coarse dominated by quartz crystals <6mm in size. Parts of this clay layer is of a more oxidised dark brownish-red colour. The slag appears to have fused with the clay suggesting that they became attached during the smelt when the high temperatures would have been sufficient to melt both fabrics. This example clearly solidified on the inside wall of the furnace.

01/02/10 (5)

Appendix C.2.12 – FS5

Characteristic features	Shaped convex undulated base (plano-convex), medium to rough top surfaces with no to few large protrusions, reasonably thin profiles/thicknesses
Size range	From the smallest fragment 49mm in length, 35mm in width and 26mm in thickness to the largest fragment/cake 316mm in length, 330mm in width and 103mm in thickness
Locations in which found	25/01/10 (6), 26/01/10 (7) (8), 28/01/10 (1), 29/01/10 (1), 30/01/10 (1), 01/02/10 (6) (8), 03/02/10 (3) (4) (6) (11) (12) (13), 05/02/10 (3) (4) (6) (7), 08/02/10 (1) (3) (9) (10), 09/02/10 (2) (6), 11/02/10 (6), 12/02/10 (1) A3 C19 (5) (6) (7) (8), 16/02/10 (2) (5) (6), 18/02/10 (2) (3) (4) (6), 19/02/10 (3) (5) (6), 22/02/10 (4), 23/02/10 (4) (6) (7), 24/02/10 (3) (4), 26/02/10 (8), 27/02/10 (6) (7)

Type 5 slags are the most widely distributed furnace slag in the assemblage being found in the most locations. Their main characteristic features are their slightly convex (in one direction) usually undulated bottom surfaces, their flattish or slightly concave medium to rough top surfaces and thin profiles. Slags of this type were found in locations 25/01/10 (6), 26/01/10 (7) (8), 28/01/10 (1), 29/01/10 (1), 30/01/10 (1), 01/02/10 (6) (8), 03/02/10 (3) (4) (6) (11) (12) (13), 05/02/10 (3) (4) (6) (7), 08/02/10 (1) (3) (9) (10), 09/02/10 (2) (6), 11/02/10 (6), 12/02/10 (1) A3 C19 (5) (6) (7) (8), 16/02/10 (2) (5) (6), 18/02/10 (2) (3) (4) (6), 19/02/10 (3) (5) (6), 22/02/10 (4), 23/02/10 (4) (6) (7), 24/02/10 (3) (4), 26/02/10 (8) and 27/02/10 (6) (7).

The majority of the type 5 furnace slag examples are broken on all sides but all fragments have surviving original top and bottom surfaces. The exceptions are some of the largest fragments found in locations 26/01/10 (8), 30/01/10 (1), 01/02/10 (8), 05/02/10 (4) (7), 08/02/10 (1) (3), 09/02/10 (2), 12/02/10 (5) (6) (8), 18/02/10 (6) and 24/02/10 (4). These have one surviving edge remaining. The type 5 slag fragments range considerably in size from the smallest fragment 49mm in length, 35mm in width and 26mm in thickness to the largest 316mm in length, 330mm in width and 103mm in thickness. All examples have a shaped convex bottom surface and a flattish or slightly concave top surface making them plano-convex or concavo-convex in profile. The majority of the fragments are between 30 - 150mm in maximum length and 30-60mm in maximum thickness.

All slags of this type are dark grey or dark greyish-purple in colour with some different coloured surface patches. These patches range in shades of dark brown, red, purple, yellow and orange. The fragments from locations 25/01/10 (6), 30/01/10 (1) and 12/02/10 (8) also have light grey or greyish-white patches. Some of the fragments from locations 03/02/10 (4) (11) and 19/02/10 (5) appear to be crystallised with shiny fractures. The rest of the slags are not with dull coloured surfaces and fractures. None of the type 5 slags are fully magnetic but those found in locations 25/01/10 (6), 29/01/10 (1), 30/01/10 (1), 03/02/10 (3), 05/02/10 (6) (7), 08/02/10 (1) (3) (9) (10), 12/02/10 (5) (7), 16/02/10 (2) (6), 18/02/10 (2) (3) (6), 19/02/10 (3), 22/02/10 (4), 23/02/10 (6) (7), 24/02/10 (3), 26/02/10 (8) and 27/02/10 (6) (7) have magnetic patches. This indicates that they contain areas with metallic iron. The more magnetic areas seem to correlate with dark brownish-red and orange patches observed on the surfaces. This colouration may therefore be oxidisation of the more iron rich parts of the slags.

Most slags of this type have a similar top surface morphology. All slag top surfaces are covered in very small protrusions giving them a coarse sandpaper texture. In addition, most have small to medium projections of material varying in sharpness giving them an overall mid to rough texture. Most examples do not have any major projections of material with their surfaces flat or slightly concave. The slightly concave surfaces are found in locations 28/01/10 (1), 03/02/10 (3) (6) (11), 08/02/10 (10), 12/02/10 (7), 18/02/10 (4), 22/02/10 (4) and 27/02/10 (6). They are curved in one direction/plane (like a roof gutter) suggesting that these slags may have solidified at the base of the furnace between the furnace bottom and the furnace wall. However, due to their small and fragmentary nature it is difficult to determine. The top surfaces are for the most part solid with no to very few small spherical or globular voids. Some of the fragments from locations 30/01/10 (1), 03/02/10 (12), 05/02/10 (3) (7), 08/02/10 (1) (3), 09/02/10 (2), 18/02/10 (6) and 23/02/10 (6) (7) and have very rough top surfaces. They tend to be more agitated than the majority with many medium sized projections. Some of these projections appear rounded but most are sharp and angular making the top surfaces uneven. In addition to the sharp surface projections most examples also have charcoal impressions up to 40mm but mainly <20mm in size. These add to the rough nature of the surfaces. The surviving edges on the fragments from the locations mentioned above are rounded and have a similar surface texture to the top surfaces.

The bottom surfaces of the type 5 furnace slag fragments are also all very similar. They are all flattened or slightly convex suggesting that they solidified against a hard surface. Most are low to medium rough in texture. They are even with no major protrusions of material. The majority are undulated with very small rounded rises and dips in the surface. In some cases these small material rises are rougher to the touch with very small sharp protrusions. The undulations are similar to those found on the bottom surfaces of tap slags but differ slightly in that the surfaces are not shiny and the undulations not as well defined (larger and more uneven). It does not appear like these fragments flowed over small stones but more likely pooled or rested on a hard surface relatively free of debris. Due to their convex curvature and thin profiles it is possible that these slags solidified against the inside of the furnace wall. In support of this are the fragments recovered from locations 25/01/10 (6) and 26/02/10 (8) which have some reduced clay adhering to the bottom surfaces. In parts this clay has chipped off revealing a similar bottom surface texture to the other examples in this slag type. The clays on these examples appears to be medium coarse with quartz crystals mostly <2mm. The clays do not appear to have significantly reacted with the slag with large portions having chipped off and no to very little vitrification. Of interest is the fact that many bottom surfaces are cracked with minor fissuring visible on the surfaces. A few fragments (particularly those found in locations 01/02/10 (8) and 03/02/10 (13) have imprinted coarse sandpaper textured surfaces similar to some of the type 1, 1.1 and 1.2 furnace slags. Although the majority of the fragments do not have any charcoal imprints on the bottom surfaces, a few do with very few impressions <15mm in size. On the whole the bottom surfaces are solid with very few to no spherical voids.

Since all type 5 furnace slag fragments have broken edges a good cross section can be seen. These reveal that they vary considerably in porosity. The majority are solid to semi-porous with some randomly distributed spherical and globular voids up to 18mm but mostly <10mm in size. Those found in locations 03/02/10 (13), 05/02/10 (6), 16/02/10 (5), 19/02/10 (6) and 23/02/10 (6) on the other hand are more porous with a greater quantity of spherical and globular voids.

25/01/10 (6)

28/01/10 (1)

29/01/10 (1)

01/02/10 (8)



03/02/10 (6)



03/02/10 (11)



05/02/10 (4)



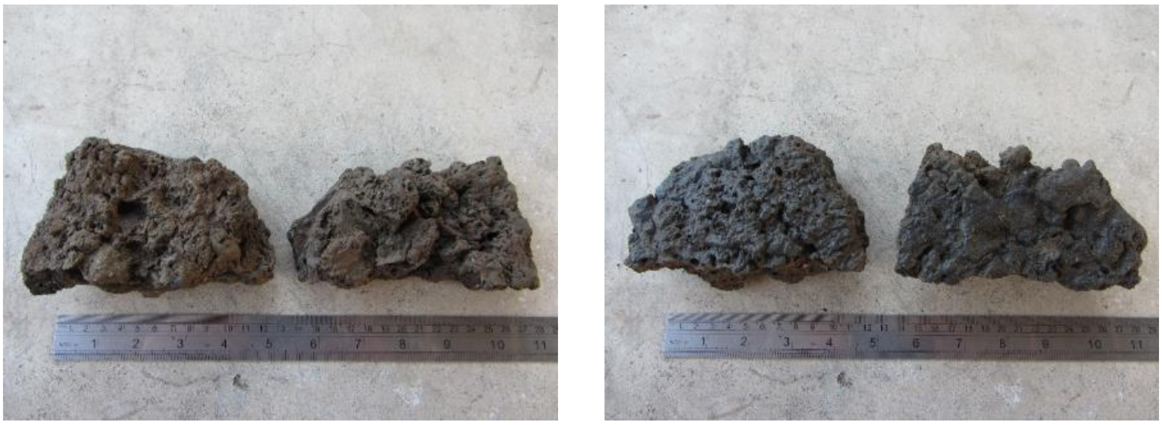
08/02/10 (3)


08/02/10 (10)


12/02/10 (7)


18/02/10 (4)


23/02/10 (4)



23/02/10 (7)

24/02/10 (3)

27/02/10 (6)

25/01/10 (6)


08/02/10 (1)

Some of the fragments recovered from locations 26/01/10 (8), 30/01/10 (1), 03/02/10 (3), 05/02/10 (3) (7), 09/02/10 (2), 18/02/10 (6) and 24/02/10 (4) are larger in size than the average type 5 furnace slags. These have similar top and bottom surface morphologies of the smaller examples but do have some features which deserve special mention. They all appear to have fully convex bases (curved in all directions) suggesting that they may have solidified at the bottom of the furnaces. Both fragments from 30/01/10 (1) and 09/02/10 (2) have an even depression on one edge of their top surfaces covering between 1/5 and 1/4 of the surface area. This dip is interesting because there are no major protrusions and the slag appears to have been well molten being mid to coarse sandpaper in texture. Unfortunately both fragments are broken on that edge so the original size of these depressions cannot be ascertained. They could be tool marks but are more likely natural. If indeed these fragments solidified at the bottom of the furnace they could be an area which was drained of slag perhaps through tapping. On the other hand if these fragments solidified against the inner furnace wall they could represent the area around the tuyere which would have been subject to higher temperatures due to the greater air flow.

Another interesting feature is found on the fragment from 05/02/10 (7) which is broken into three pieces. The top surface is agitated and uneven but there is one large projection which protrudes 40-50mm above the rest of the surface. It is rough with many smaller sharp protrusions and some more molten rounded ones. It almost looks like tap slag dripping down into the larger cake. However, the projection looks almost complete and its rough texture suggests that it is more likely furnace slag.


26/01/10 (8)

30/01/10 (1)



03/02/10 (3)



05/02/10 (3)



05/02/10 (7)

09/02/10 (2)

18/02/10 (6)

18/02/10 (6)

24/02/10 (4)

Two furnace slag cakes/fragments from 25/01/10 (6) and 11/02/10 (6) are of an unusual shape. They are both curved fragments that look like they solidified against the interior furnace wall. The fragment from 11/02/10 (6) is 169x96x52mm in size. It appears to be a layer of rough slag which solidified at the base of the furnace wall. One edge is flat and thicker, tapering the further up it goes. Three edges are broken but the exterior and interior surfaces remain intact. The exterior/back (convex) surface of the fragment is rough with many small undulations and a bit of porosity. It looks like marks that would be left by the furnace wall which has mostly chipped off. There is some furnace clay remaining towards the base but it is very reduced and of the same type as the rest of the clay fragments found in the same location (mid coarse). Protruding from the flat base is a thin lip of well molten looking slag which seems to have penetrated underneath the furnace wall by about 20-30mm. The interior (concave) surface is coarse sandpaper rough with many very small sharp protrusions and seems to have had a thin slag crust which has partially chipped in some areas to reveal spherical and irregular porosity underneath (up to 11mm in size). The inner surface is a dark orangey-reddish-brown colour but the slag appears to be dark grey on the fractures. It also has a few sparse charcoal impressions up to 11mm in length on the interior surface.

The fragment from 25/01/10 (6) is 278x195x51mm in size. It is also a curved fragment broken on all edges but with the interior and exterior surfaces intact. The exterior (convex) surface is covered in a layer of dark grey reduced clay which is heavily abraded and broken. This clay is mid coarse with small quartz crystals mostly <3mm but up to 10mm in size. In some areas the clay is vitrified with some spherical porosity suggesting that the slag and clay are well fused and must have made contact at very high temperatures. The interior (concave) surface is coarse sandpaper to mid rough in texture. It has many very small and a few small sharp protrusions. The surface is dark grey with many dark brownish-red/purple patches which are magnetic suggesting metallic iron content.

11/02/10 (6)


25/01/10 (6)

Appendix C.2.13 – FS5.1

Characteristic features	Curved (convex) bottom surfaces, mostly broken, varying top surfaces and porosity
Size range	From the smallest fragment 57mm in length, 51mm in width and 41mm in thickness to the largest 203mm in length, 152mm in width and 106mm in thickness.
Locations in which found	29/01/10 (5), 01/02/10 (1) (2) (3) (5) (6), 03/02/10 (9) (11), 05/02/10 (2), 08/02/10 (1) (2) (10), 12/02/10 (1) A8 C19, 16/02/10 (1), 17/02/10 (2) (5), 21/02/10 (9), 22/02/10 (3), 23/02/10 (10) (12), 24/02/10 (3), 25/02/10 (8), 26/02/10 (8), 27/02/10 (6)

Several type 5.1 furnace slags have been identified in the assemblage. The furnace slags are not as diagnostic as some of the previous sub-types. Their major characteristic features are their curved (convex) undersides, the fact that most are broken and their varying surface textures and porosity. They are not as homogenous as the type 5 examples but seem to be fragments of larger slag consolidations that have made contact with the furnace walls or base. Type 5.1 slag were found in locations 29/01/10 (5), 01/02/10 (1) (2) (3) (5) (6), 03/02/10 (9) (11), 05/02/10 (2), 08/02/10 (1) (2) (10), 12/02/10 (1) A8 C19, 16/02/10 (1), 17/02/10 (2) (5), 21/02/10 (9), 22/02/10 (3), 23/02/10 (10) (12), 24/02/10 (3), 25/02/10 (8), 26/02/10 (8) and 27/02/10 (6).

The majority of the type 5.1 furnace slags are broken on all edges but most have part of their top and bottom surfaces remaining enabling identification. The fragments range in size from the smallest 57mm in length, 51mm in width and 41mm in thickness to the largest 203mm in length, 152mm in width and 106mm in thickness.

Like many other furnace slag sub-types, all examples are dark grey in colour with many different coloured patches on their surfaces. These patches vary in shades of dark brown, red, purple, yellow and orange. The slags found in location 12/02/10 (1) also have large light to whitish grey patches. The surfaces of the fragments from locations 01/02/10 (1), 08/02/10 (1), 22/02/10 (3) and 27/02/10 (6) are dominated by a dark orangey-brown and yellowy-brown colouration. Most slags of this type have dull coloured surfaces but some found in locations 01/02/10 (2) (5), 05/02/10 (2), 08/02/10 (10) and 23/02/10 (12) are shiny and crystallised. On most of those large fayalite crystal formations can be seen on fresh fractures.

None of the slag fragments are fully magnetic but those found in locations 01/02/10 (3), 03/02/10 (11), 05/02/10 (2), 08/02/10 (2) (10), 12/02/10 (1) A8, 16/02/10 (1), 17/02/10 (2), 21/02/10 (9), 22/02/10 (3), 23/02/10 (12), 24/02/10 (3) and 26/02/10 (8) have magnetic patches. This suggests that there is some metallic iron content in some parts of these slags. Of special interest is the fragment from 01/02/10 (3) which has a large heavily magnetic protruding lump on its top surface. This lump is centrally positioned and approximately 40mm wide and 40mm in height taking up 1/4 of the top surface area. It is mid rough and coarse sandpaper in texture covered in dark brownish-reddish-orange colouring. It is worth mentioning that in most cases the magnetic areas are associated with darker brownish-red and orange patches. This suggests that the metallic rich areas may have oxidised.



01/02/10 (3)

The majority of the type 5.1 furnace slags have mid rough to rough top surfaces. These vary slightly in morphology but most are flat with no major protrusions (except the example from 01/02/10 (3)). The protrusions are mainly small to medium and sharp to the touch with angular edges. Some examples have more rounded flow-like protrusions while others have crimpled parts where slag has folded and bunched on the surface (like skin on milk). The examples in 12/02/10 (1) are more agitated than the others with more protrusions and less even surface. Most of the mid rough top surfaces are solid with no to very few spherical voids. However, some fragments recovered from 01/02/10 (5), 05/02/10 (2), 08/02/10 (1), 17/02/10 (2) and 23/02/10 (10) (12) have broken or partially broken top surfaces revealing many spherical and globular voids. It appears that these slags would have had a thin layer of slag covering the top surface which subsequently broke after deposition. These voids and breaks have left sharp edges making most of these surfaces rough to the touch. The largest example from 08/02/10 (10) has an almost perfectly flat and smooth top surface with a few broken angular protrusions. It suggests that the top part of the slag broke off revealing a very large flattened void which now covers the entirety of the surface. The majority of the type 5.2 slag fragments also have charcoal impressions visible on the top surfaces. These impressions are most often faint and shallow and up to 60mm in size but mainly <20mm.

The bottom surfaces are all evenly convex with no major protrusions of material. They are similar to the type 1 and 1.2 furnace slags except that most do not appear to curve in all directions (like a bowl) but only on a single plane (like a gutter). This suggests that they probably solidified against the furnace wall or at the base of the furnace between the base and wall. The majority have medium rough or coarse sandpaper textured bases. They are dominated by many very small sharp protrusions. In some cases like on the fragments from 05/02/10 (2) and 08/02/10 (1) (10) these protrusions are created by many very small charcoal impressions up to 20mm but mainly <6mm. On many there are also quartz crystal inclusions up to 12mm but mainly <4mm in size. Some of the fragments from locations 17/02/10 (2) (5), 21/02/10 (9), 22/02/10 (3), 23/02/10 (10) and 26/02/10 (8) also have more undulated bottom surfaces. These are of low roughness with small rounded undulations similar to what is found on tap slags but not as smooth (some gritty material on surfaces and quartz inclusions).

Of special interest are some of the fragments from 01/02/10 (3), 08/02/10 (2) and 16/02/10 (1) which have bottom surfaces covered in dark grey reduced clay. This clay is coarse on all fragments dominated by quartz crystals up to 16mm but mainly <5mm in size. This clay is broken but there seems to be a significant level of vitrification where they meet the slags. This fusion of both material suggests that they made contact at very high temperatures probably during the smelting process. In these cases it is likely that the slag fragments solidified on the interior of the furnace wall.

Since all the type 5.1 furnace slags have broken edges, a good cross section through them can be observed. They vary considerably in porosity but the majority are solid to semi-porous with some randomly spread spherical and globular voids up to 14mm but mainly <8mm in size. Some horizontally elongated voids up to 74mm in size were also present on the fragments in locations 29/01/10 (5), 01/02/10 (6), 05/02/10 (2), 08/02/10 (10) and 12/02/10 (1 – A8) (1 – C19). The examples in locations 01/02/10 (5), 03/02/10 (5), 05/02/10

(2), 21/02/10 (9), 23/02/10 (10) (12) and 27/02/10 (6) on the other hand are porous with a greater percentage of randomly spread spherical and globular voids up to 15mm in size.

29/01/10 (5)

01/02/10 (1)

01/02/10 (2)


01/02/10 (5)

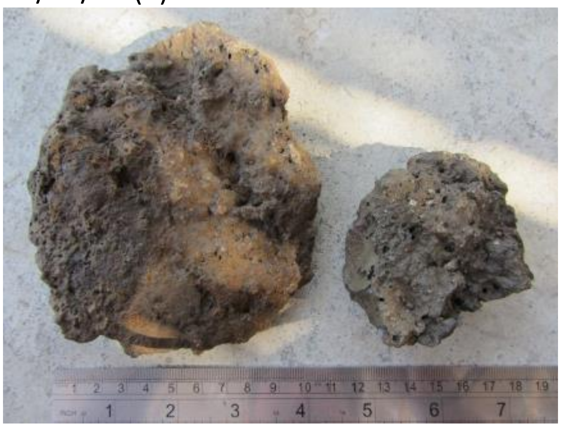

01/02/10 (6)


03/02/10 (9)


05/02/10 (2)

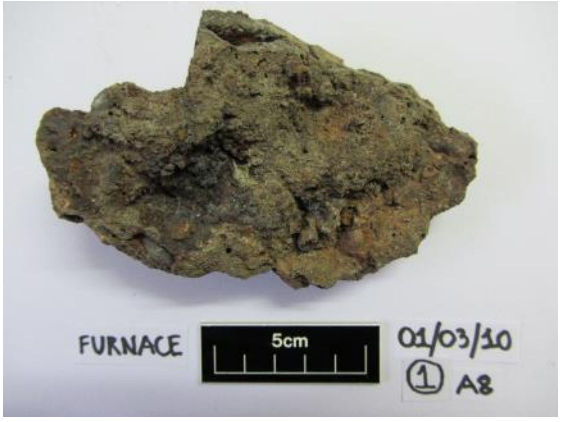

05/02/10 (2)


08/02/10 (1)

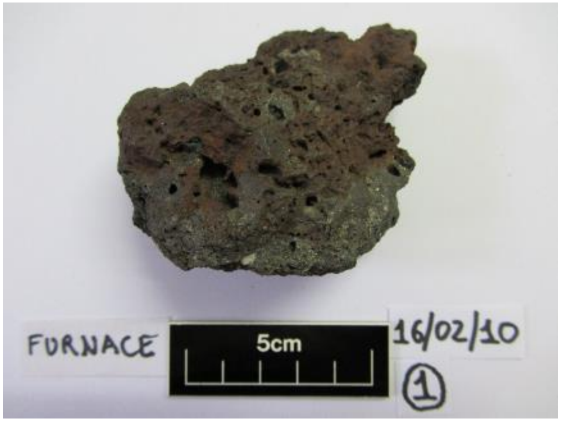



08/02/10 (2)


08/02/10 (10)



12/02/10 (1 – A8)



16/02/10 (1)


17/02/10 (2)


22/02/10 (3)


23/02/10 (10)


23/02/10 (12)


24/02/10 (3)


25/02/10 (8)

27/02/10 (6)

Appendix C.2.14 – FS5.2

Characteristic features	Small cylindrical shaped slag, channelled with one tapering end
Size range	From the smallest fragment 72mm in length, 14mm in width and 20mm in thickness to the largest 198mm in length, 153mm in width and 91mm in thickness
Locations in which found	01/02/10 (2), 02/02/10 (8), 06/02/10 (2), 08/02/10 (9) (10), 09/02/10 (7), 13/02/10 (1), 23/02/10 (1), 26/02/10 (3)

Very few type 5.2 furnace slag fragments were recovered. Their main characteristic features are their small cylindrical shapes usually with a thicker end tapering towards the other. These slags were found in locations 01/02/10 (2), 02/02/10 (8), 06/02/10 (2), 08/02/10 (9) (10), 09/02/10 (7), 13/02/10 (1), 23/02/10 (1) and 26/02/10 (3).

All of the type 5.2 slags are broken with at least one end missing. All examples have remaining top and bottom surfaces enabling identification. They vary in size from the smallest fragment 72mm in length, 14mm in width and 20mm in thickness to the largest 198mm in length, 153mm in width and 91mm in thickness. The majority are between 72-134mm in length, 25-65mm in width and 25-67mm in thickness.

All slags of this type are dark grey in colour with patches varying in colour. These patches vary in shades of dark brown, red and orange. None of the slags are crystallised with all examples being dull in colour. None are magnetic except the fragment from 26/02/10 (3) which has some magnetic areas. This suggests that there is some metallic iron present in some parts.

The shape of these slags is their main characteristic feature. They are cylindrical in shape with a spherical or oval cross-section. Most are thin and elongated with surfaces that appear to have been moulded by a hard material. It is likely that these slags solidified in the furnace wall. They look like the start of tap slag flows. Due to their thin cylindrical shape it seems likely that a hole in the furnace wall was made (perhaps with a stick) to allow slag to run out of the furnace. Due to the absence of rippled top surfaces indicating that the slag was running freely, these examples would have been the part of the flow that solidified inside the furnace wall. The slag would have been constricted on all sides producing this diagnostic shape. Of special interest is the fragment from 08/02/10 (10) which has a much larger end than the others making it almost fan shaped in plan. This example seems to have furnace slag adhering creating this wider end. This end has a central depression forming almost a bowl shape which then tapers turning into a cylindrical shape. It is broken only representing approximately 1/3 of a complete bowl shape. This end is rough with many small sharp protrusions of material and charcoal impressions <22mm in size. It undoubtedly represents the furnace slag being drained out of the furnace through a tapping hole made in the furnace wall. A depression in the slag formed probably as the supply from the furnace diminished and eventually ran out leaving the slag below the tapping hole level to solidify in the furnace. None of the other examples have this feature due to their very small and fragmentary nature. However, the fragment from 13/02/10 (1) has a broken end which appears to taper more abruptly suggesting that a similar slag morphology may have been found if it was not broken.

08/02/10 (10)

All the surfaces are similar on all fragments. The surfaces on the fragments from 01/02/10 (2), 08/02/10 (10), 09/02/10 (7), 13/02/10 (1) and 26/02/10 (3) are homogenous with no clear top or bottom surface. These are coarse sandpaper to mid coarse in texture dominated by very small sharp protrusions of material (pitted surface texture). In some cases the protrusions are thin and flaky with parts that have chipped off revealing some small spherical and globular porosity underneath. Many fragments also have some small quartz inclusions (most <3mm) adhering to the surfaces which may have been picked up by contact with clay. This is especially evident on the fragment from 01/02/10 (2) which has many adhering quartz crystals all over its surface. The fragment from 12/02/10 (1) is dominated by very small charcoal impressions <10mm in size. This has left a rough surface with many very small flaky protrusions and a dark orangey-brown surface coating. The surfaces of the other fragments are similar on their undersides but their top surfaces differ slightly. Most of the top surfaces show signs of having been well molten with flow features. Most are low rough with small rounded rippled projections similar to tap slag. However, some are more agitated with sharper sometime broken protrusions. The top surface of the fragment from 08/02/10 (9) for example is dominated by charcoal impressions <10mm in size making the surface rough in texture. The thicker end of the fragment from 08/02/10 (10) is also similar.

Of special interest are the fragments from 13/02/10 (1), 23/02/10 (1) and 26/02/10 (5). Unlike the others which are broken on both ends, these have one intact end surviving. These seem to be at the thinner tapered end suggesting that they are the end of the slag flow. All these ends are similar. They are rounded with an even slag surface smooth to low rough in texture. All have very few very small sharp protrusions like seen on the rest of their surfaces but are mostly smooth and free of projections. In these cases it suggests that the slag runs were not very large and could even not have made it outside of the furnace. These may be evidence of slag plugs that solidified in a tapping hole or if the tapping hole was slightly raised from the ground surface slag may have solidified inside the hole after a significant amount ran out by dripping off the end and not necessarily creating a continuous flow.

Since all fragments of this type have at least one broken end, a good cross section can be seen. These reveal that they are all solid to semi-porous in nature with relatively few spherical and globular voids up to 13mm but mostly <6mm in size. The fragment from 13/02/10 (1) also has one large elongated void 45mm in size in its centre. Although most of the larger voids appear to be randomly distributed a few examples have concentrations of smaller spherical voids (<2mm) around the edges of the slags (just below the surface). This adds proof to the theory that they were entirely constricted on all sides preventing gas voids to escape.

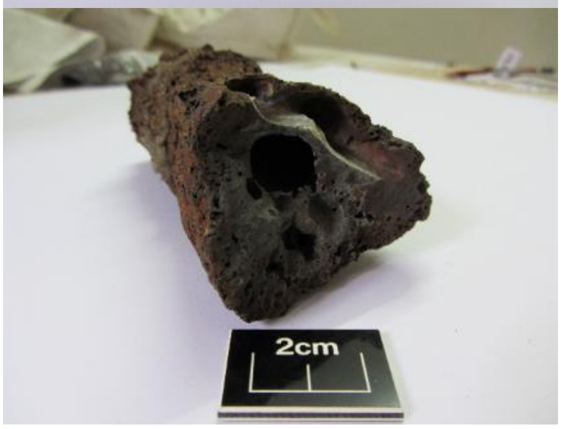
01/02/10 (2)

02/02/10 (8)

06/02/10 (2)

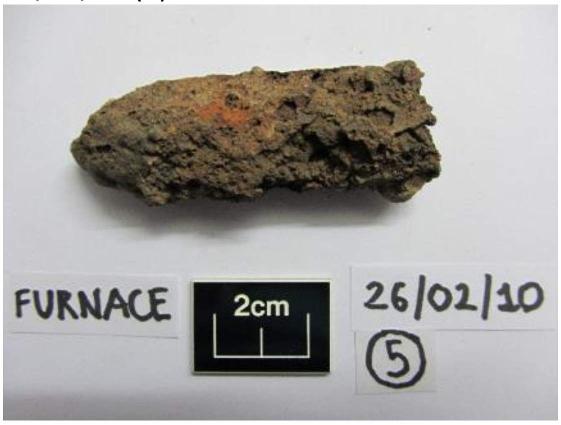
08/02/10 (9)

09/02/10 (7)



13/02/10 (1)

23/02/10 (1)



26/02/10 (3)

Appendix C.2.15 – FS6

Characteristic features	Amorphous, mostly broken edges, rough to very rough textured and very porous (honeycomb) in nature
Size range	From the smallest fragments <49mm in maximum length to the largest 210mm in length, 123mm in width and 151mm in thickness
Locations in which found	28/01/10 (5), 29/01/10 (4), 01/02/10 (8), 08/02/10 (2), 09/02/10 (6), 12/02/10 (2), 13/02/10 (8), 15/02/10 (2) (3), 17/02/10 (2), 18/02/10 (1) (5), 21/02/10 (1) (6), 23/02/10 (1) (2) (5) (8), 24/02/10 (3), 25/02/10 (1), 27/02/10 (3) (4) (7)

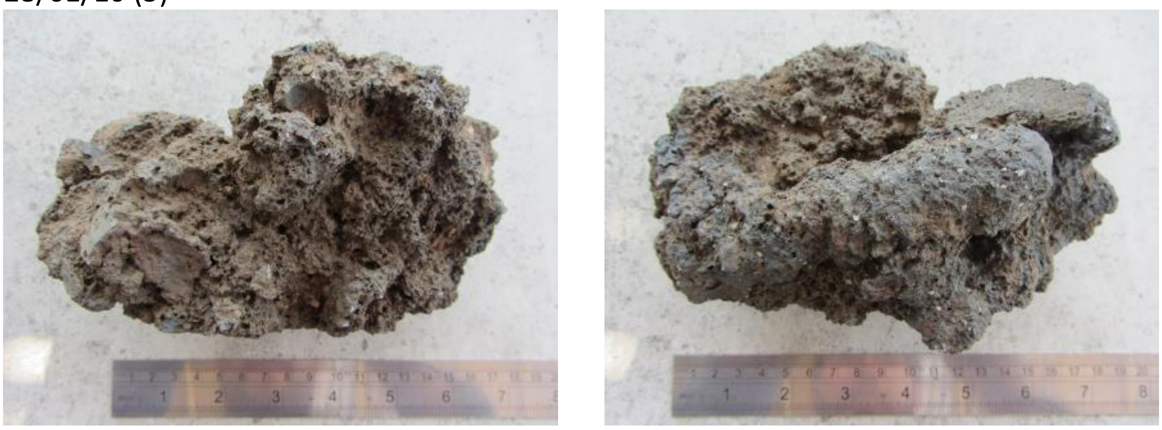
Several type 6 furnace slag fragments were recovered. Their major characteristic features are their amorphous shape, their poor preservation with most original surfaces missing, their rough to very rough texture and porous to very porous (honeycomb) consistency. Fragments of this type were found in locations 28/01/10 (5), 29/01/10 (4), 01/02/10 (8), 08/02/10 (2), 09/02/10 (6), 12/02/10 (2), 13/02/10 (8), 15/02/10 (2) (3), 17/02/10 (2), 18/02/10 (1) (5), 21/02/10 (1) (6), 23/02/10 (1) (2) (5) (8), 24/02/10 (3), 25/02/10 (1) and 27/02/10 (3) (4) (7).

All fragments are badly preserved with very few natural surfaces remaining. Most are amorphous in shape and dominated by broken edges/surfaces. All of them are light being of low density. The fragments vary in size from the smallest fragments <49mm in maximum length to the largest 210mm in length, 123mm in width and 151mm in thickness.

The majority of the type 6 furnace slags are dark grey in colour but some are more of a dark greyish-black or dark greyish-blue/purple. All have different coloured patches on their surfaces ranging in shades of dark brown, red, purple and orange. Many of the fragments (especially those found in locations 28/01/10 (5), 09/02/10 (6), 13/02/10 (8), 18/02/10 (5), 23/02/10 (1) and 27/02/10 (3)) have shiny fractures. The other fragments and the intact surfaces on the shiny ones are all dull coloured. The majority of the type 6 slags are not magnetic. However, a few magnetic patches were present on the examples from 01/02/10 (8), 13/02/10 (8), 18/02/10 (1), 25/02/10 (1) and 27/02/10 (7). This suggests that parts of these slags contain some metallic iron. Like many of the other furnace slag types, the magnetic areas are associated with dark red and orange coloured patches on the surfaces. It is also worth mentioning that they are present on fragments that appear slightly denser than the majority.

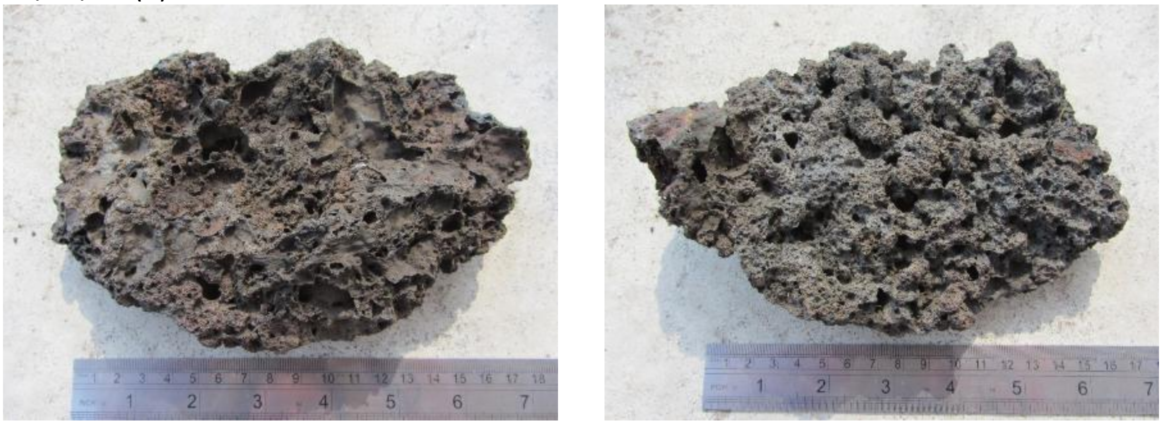
The surfaces are mostly broken revealing porous to very porous slag. Thin layers/flanges of slag are present in between the voids. These are sharp and angular making the slags rough to very rough in texture. The voids are mainly spherical and globular up to 15mm in size but mostly <7mm. Most fragments have a mixture of these small voids and very small <2mm ones giving an almost honeycomb texture. Due to the high quantity of voids some form networks where several voids have amalgamated. The fragment in 12/02/10 (2) also has a few horizontally elongated/flattened voids up to 35mm in length. A few fragments have remains of original surfaces. These are either coarse sandpaper to mid rough in texture with very small to small sharp protrusions of material or very thin crusts (<1mm) of smooth to low rough slag with large rounded undulations. Some of these rougher original surfaces have charcoal impressions mostly <18mm in length but the fragments in 29/01/10 (4) and 15/02/10 (2) have impressions up to 34mm and 50mm respectively.

28/01/10 (5)



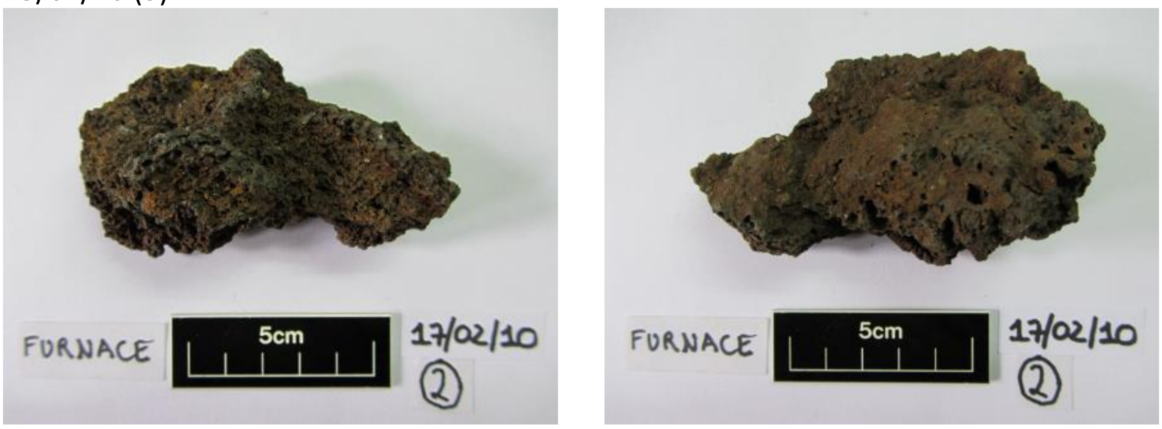
29/01/10 (4)

13/02/10 (8)



15/02/10 (2)

15/02/10 (3)

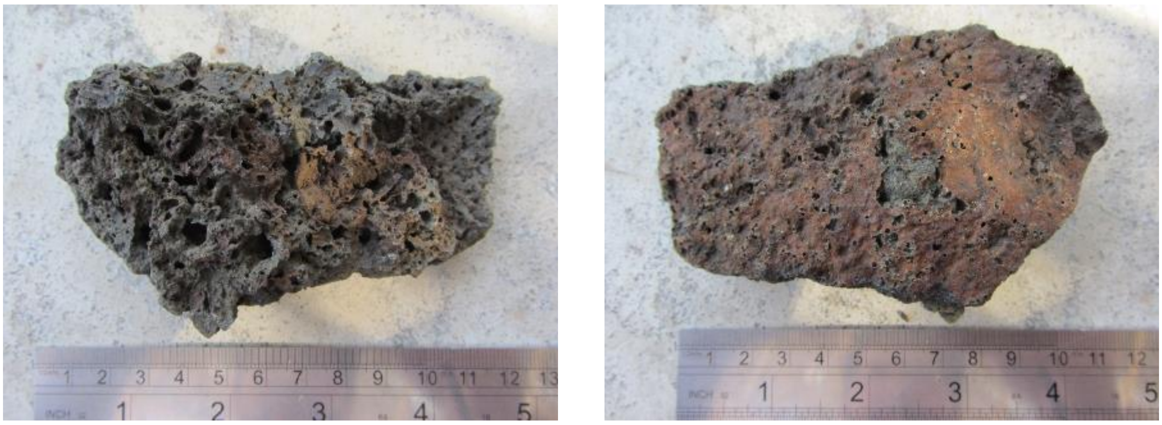


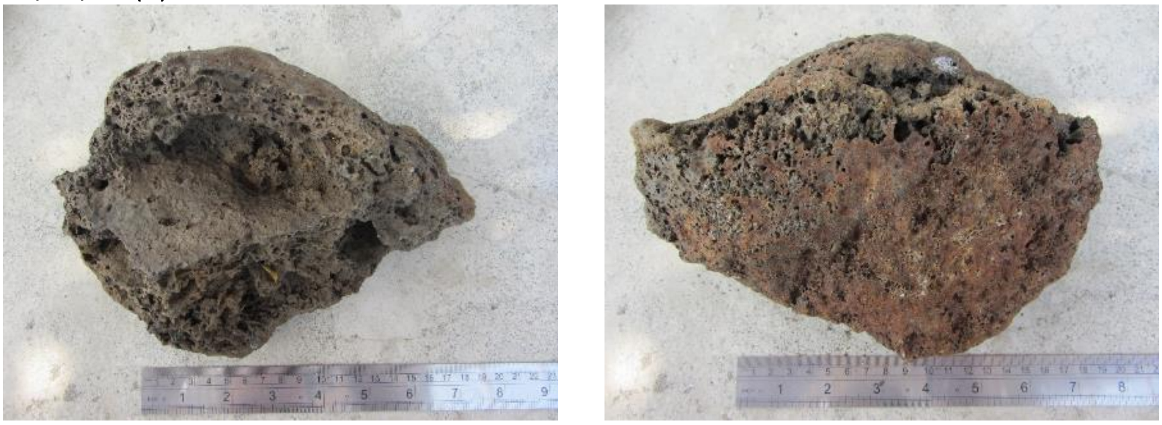
17/02/10 (2)

23/02/10 (2)

25/02/10 (1)

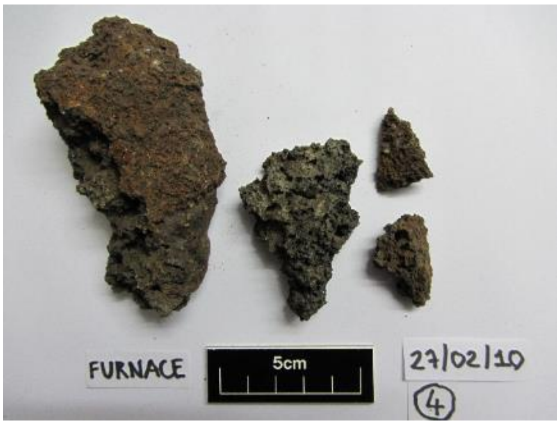
The fragments from locations 08/02/10 (2), 09/02/10 (6), 18/02/10 (1), 21/02/10 (1) (6) and 27/02/10 (4) have one side which appears to be shaped. These surfaces are convex and smooth to low rough in texture with no major protrusions. They are all made of a very thin layer of slag <1mm thick which has chipped off in many places to reveal the same heavy porosity underneath as all other fragments. These thin layers are undulated with very small rounded protrusions suggesting that the slags made contact with a hard surface. It is likely that these examples solidified against the furnace wall or at the base of the furnace.


08/02/10 (2)


09/02/10 (6)

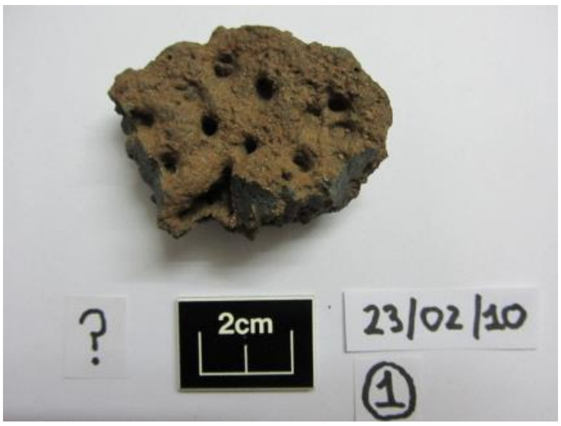

18/02/10 (1)

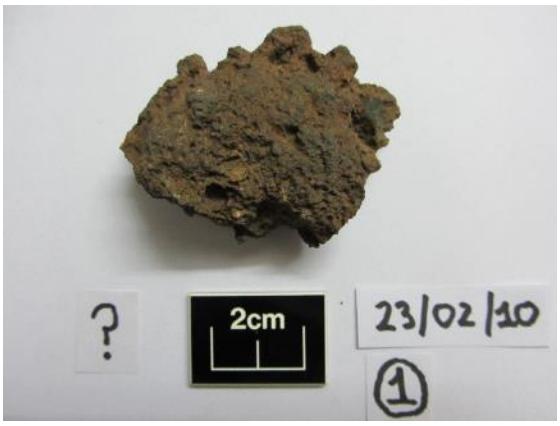

21/02/10 (6)



27/02/10 (4)

Of special interest are the fragments recovered from locations 23/02/10 (1), 23/02/10 (8) and 27/02/10 (3). These have evenly spaced voids on one of their surfaces. The one from 23/02/10 (1) has a series of at least 8 regular and evenly spaced holes on one side about 3-4mm in diameter going at a depth of up to 5mm. The one from 23/02/10 (8) is similar with at least 10 holes on one surface up to 10mm in diameter and evenly spaced. The one from 27/02/10 (3) also has a regular pattern of spherical voids on its surface. These vary in size from 2-7mm and occur in concentrations. They are between 5-15mm in depth and look to be cylindrical voids. The fragments all vary in surface texture and the example from 23/02/10 (1) is less porous (low porosity) and denser. Both fragments from 23/02/10 (1) and 27/02/10 (7) have shiny fractures. Their peculiar void concentrations leads to suggest that they may have been prodded with a tool when they were still viscous (partially molten – perhaps during removal from hearth or furnace).





23/02/10 (1)


23/02/10 (8)

27/02/10 (2)

It may also be worth mentioning the fragments from location 01/02/10 (8). The majority of the slag fragments recovered from this location are of this type. The sheer quantity of these porous slags suggests that a different technology may have been employed. The slags themselves also differ slightly from the others in this type. They are usually more complete with some surviving original surfaces and some small projections of material. They are amorphous in shape with a coarse sandpaper texture. The original surfaces are made of a very thin layer/crust of slag (<0.5mm) with many very small sharp protrusions. This crust has chipped off in many areas revealing porous to very porous slag dominated by very small spherical voids (<2mm) giving the slags a honeycomb appearance. All examples have some broken edges revealing a good cross section. The porosity seems evenly distributed throughout the fragments making them reasonably light in density.

01/02/10 (8)

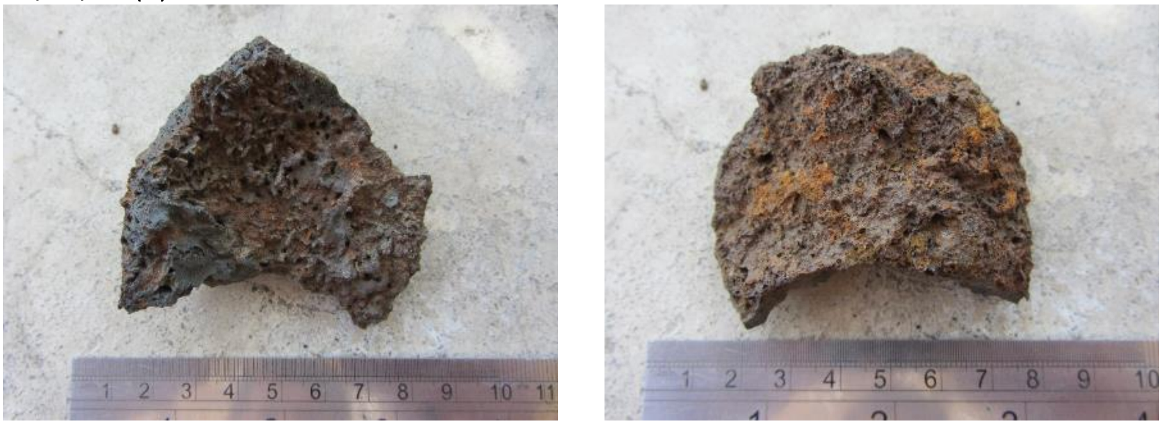
Appendix C.2.16 – FSND

Characteristic features	Non-diagnostic, small broken fragments
Size range	<139mm in maximum length
Locations in which found	30/01/10 (1), 02/02/10 (1), 03/02/10 (14), 09/02/10 (2) (4), 12/02/10 (1) (8), 13/02/10 (1), 19/02/10 (2) (5), 21/02/10 (5) (7)

A few non-diagnostic slag fragments were recovered from locations 30/01/10 (1), 02/02/10 (1), 03/02/10 (14), 09/02/10 (2) (4), 12/02/10 (1) (8), 13/02/10 (1), 19/02/10 (2) (5) and 21/02/10 (5) (7). They are all dark grey in colour with different coloured patches varying in shades of dark brown, red, purple and orange. The fragments in locations 30/01/10 (1), 12/02/10 (1), 19/02/10 (2) and 21/02/10 (7) are very small and fragmentary with many broken edges meaning that they cannot be identified. The fragment from 02/02/10 (1) is a medium sized amorphous lump without any defining morphological characteristics and the example from 21/02/10 (5) is a very small broken crust-like fragment. Even though these fragments cannot be attributed to any of the furnace-slag sub-types described above their colouration suggests that they are smelting waste.

02/02/10 (1)


19/02/10 (2)


21/02/10 (5)


21/02/10 (7)

The fragments recovered from 30/01/10 (1), 03/02/10 (14), 09/02/10 (2) (4), 12/02/10 (8), 13/02/10 (1), 19/02/10 (5) and 21/02/10 (5) are small and are broken on most surfaces. However, they are solid with few spherical and globular voids <10mm in size. Some appear to have remains of a top or bottom surface but due to their small size they cannot be positively attributed to one of the furnace slag sub-types described above. On the other hand, their solid nature with clean breaks suggests that they would have been part of larger perhaps plano-convex slag cakes similar to the type 1 furnace slags.

03/02/10 (14)

09/02/10 (4)



12/02/10 (4)



13/02/10 (1)

19/02/10 (5)

Appendix C.3 – Smithing Slag

Some potential smithing slag cakes and fragments were recovered. Several sub-types were identified and these will be described in this section. Table 1 below shows the quantity, weight (grams), size (mm), colour and porosity of the smithing slags by type found in each location. Photographs relate to the text directly preceding them.

Table 1 - Table showing the weight (grams), size (mm), colour and porosity of smithing slags by type in each location.

Location	Type (SS)	Weight	No	Colour	Size			Porosity			Magne-tism
					L	W	T	Q	Shape	Size	
01/02/10 (8)	2	682	4	Dark greyish blue – mid to dark grey + brownish orange + purple patches	59-87	42-89	31-31	L-SP	S G I	<4	high
02/02/10 (8)	1	110	1	Dark grey – dark red patches	60	60	27	P	S G	<5	
	3	160	3	Dark grey – dom dark brownish red + orange patches	45-70	28-46	8-13	S-SP	S G	<3	high
	2	80	1	Dark grey – dom dark orangey brown	60	42	23	S	I	<2	high
03/02/10 (1)	1	1802	3	Dark grey – dom yellowy orange + brownish red patches – one base dark purple + dark reddish brown	100-125	79-105	43-63	S-SP	S G I	<10	
03/02/10 (6)	1	240	1	Dark grey/purple – dom brownish orange	72	63	55	P	S G I	<4	patches
03/02/10 (14)	1	230	1	Dark grey/purple – dom brownish orange	104	55	40	SP	S G I	<4	patches
03/02/10 (15)	3	200	10	Dark grey purple – dark brownish orange patches	22-17		9-17	SP-P	S G I	<3	medium – high
05/02/10 (3)	3	20	1	Dark grey purple – dark brownish red + orange patches	43	39	13	S			high
05/02/10 (5)	1	982	1	Dark greyish blue – dom mid greyish brown + dark brownish red	85	76	41	P	S G	<8	
	1.1		1	Dark greyish blue – dom mid greyish brown + dark brownish red	117	80	87	SP	S G I	<30	
08/02/10 (1)	3	50	3	Dark grey – dark orangey brown patches	48-50	38-43	13-8	S-SP	S G	<3	low
08/02/10 (4)	3	20	2	Dark grey	31 25	25 25	7 7	L-SP	S G	<2	low
08/02/10 (9)	2	110	1	Dark grey – dom brownish orange + orange	58	46	25	L-SP	S G	<6	high
09/02/10 (5)	1	193	1	Dark grey – dom dark yellow + orangey brown – dark brownish red patches	105	71	30	SP-P	S	<1	patches
12/02/10 (1)	2	601	lot	Dark grey – dom orangey brown + dark brownish orange – reddish brown patches	<70			SP - P	S G	<4	patches to high
	3	28	2	Dark grey – dom dark reddish purple + dark orangey brown	Upto 60	40	5	SP	S G	<2	low
12/02/10 (3)	1	870	1	Dark grey – dom dark brownish red + orange patches	116	96	75	SP	S G	<8	high

Location	Type (SS)	Weight	No	Colour	Size			Porosity			Magne-tism
					L	W	T	Q	Shape	Size	
	2	175	1	Dark greyish blue – dom dark brownish yellow orange + dark brownish red	80	42	39	S	S G	<2	high
12/02/10 (6)	2	584	lot	Dark grey – dom dark yellowy orange + dark brownish red	<68			SP - P	S G	<8	high
17/02/10 (1)	2	100	1	Dark grey – dom orange + dark red patches	64	41	30	SP	S G	<2	high
	1	2260	1	Dark grey – dom brownish orangey yellow + purple – mid grey patches	186	135	52	S-L	S G	<5	
17/02/10 (5)	1	666	1	Dark grey – dark purple + whitish grey + orangey brown patches – base dom brownish orange	112	101	45	SP-P	S G	<6	
17/02/10 (6)	1	1686	4	Dark greyish blue/purple – mid grey + yellowy orangey brown + dark reddish brown patches	86-100		37-62	S-SP	S G	<10	patches
	1	1460	1	Dark greyish blue – dom reddish orangey brown + mid grey patches	160	130	62	L-	S G I	<17	
18/02/10 (4)	3	40	1	Dark grey – dark brown + red patches	55	40	15	SP	S G	<5	patches
21/02/10 (1)	1	524	2	Dark grey – dark brownish red patches	67 106	47 75	44 39	S-L	S G E few	<3 <24	
	2	31	1	Dark grey – dom mid grey + orangey brown	38			L – SP	S G	<10	low
21/02/10 (4)	2	30	1	Light grey – dark brown + reddish brown patches	36			SP	S G	<2	medium
21/02/10 (5)	2	70	2	Light grey – dark orangey brown + dark red purple patches	<44			S			high
21/02/10 (9)	1	312	1	Dark grey – dom orangey + reddish brown	90	71	60	SP	S G	<8	high
	2	363	4	Dark grey – dom orangey + reddish brown – some dark purple patches	<70			L-SP	S G	<10	1 high
24/02/10 (2)	2	50	1	Dark grey purple – dom reddish brown	45			SP	S G	<6	high
25/02/10 (1)	1	153	1	Dark greyish blue – dom dark reddish brown – dark brownish red patches	84	76	27	SP-P	S G	<10	
25/02/10 (2)	2	39	1	Dark grey/purple – dark orangey brownish red patches	43			S	S	<8	high
25/02/10 (3)	2	117	1	Dark grey/purple – dark orangey brownish red patches	60			S	S	<4	high
27/02/10 (6)	1	168	1	Dark grey – dom dark orangey brown + dark reddish brown	64	50	28	S			

Key:

Size
L – length W – width T - thickness

Porosity Q - quantity
S – solid SP – semi porous P – porous VP – very porous

Porosity shape
S – spherical G – globular E – elongated N – networked I – irregular

Appendix C.3.1 – SS1

Characteristic features	Small plano-convex or concavo-convex cakes; circular or oval in plan; well molten top surface
Size range	From the smallest fragment 60mm in length, 60mm in width and 27mm in thickness to the largest 186mm in length, 135mm in width and 52mm in thickness. Some of the larger fragments are up to 87mm thick.
Locations in which found	02/02/10) (8), 03/02/10 (1) (6) (14), 05/02/10 (5), 09/02/10 (5), 12/02/10 (3), 17/02/10 (1) (5) (6), 21/02/10 (1) (9), 25/02/10 (1), 27/02/10 (6)

Slag fragments and cakes of this type are probably the most diagnostic as being the result of the smithing process. The major characteristic features which defines this type are their generally small size, plano-convex or concavo-convex profiles and circular or oval plans. They are likely cakes of slag that accumulated and solidified at the bottom of smithing hearths. Slag of this type was recovered from locations 02/02/10) (8), 03/02/10 (1) (6) (14), 05/02/10 (5), 09/02/10 (5), 12/02/10 (3), 17/02/10 (1) (5) (6), 21/02/10 (1) (9), 25/02/10 (1) and 27/02/10 (6).

The majority of the slag cakes are complete or almost complete with only small fractures on their periphery. They vary in size from the smallest fragment 60mm in length, 60mm in width and 27mm in thickness to the largest 186mm in length, 135mm in width and 52mm in thickness. However, most are smaller than 117mm in length, 101mm in width and 55mm in thickness. Some of the larger fragments are up to 87mm thick. Although the majority are almost complete, some of the slags found in locations 03/02/10 (6) (14), 17/02/10 (5) and 25/02/10 (1) are fragmentary with only parts remaining. Nonetheless they retain enough features (usually part of their top and bottom surfaces) to be identified as this type.

The slag cakes and fragments are dark grey or dark greyish blue in colour but often dominated by dark brownish-red or varying shades of orangey-yellowy-brown. This colouration may be due to soil staining or oxidisation (corrosion) of parts with more metallic iron content. Most of these coloured patches appear to be gritty (medium to coarse sandpaper rough) in texture with many very small protrusions of material and sometimes small quartz inclusions (<2mm).

The top surfaces all vary slightly in texture. Some of the fragments from locations 03/02/10 (1) (6) (14), 12/02/10 (3), 17/02/10 (6) and 21/02/10 (9) have rough agitated top surfaces with small to medium protrusions of material. These surfaces are generally flat (plano) or uneven due to the projections. In some cases these protrusions are broken leaving sharp breaks while on others the surfaces are more abraded and less sharp. The fragments from 03/02/10 (14) and 12/02/10 (3) are particularly agitated with larger protrusions. Those in locations 03/02/10 (1) (6) (14), 17/02/10 (6) also have a few charcoal voids (sometimes with remains of charcoal in them) up to 23mm in size present on their top surfaces. These usually contribute to the roughness by leaving small sharp flanges of slag around the edges of these voids.

Of special interest are some of the fragments/cakes from locations 02/02/10 (8), 05/02/10 (5), 17/02/10 (1) (5) (6), 21/02/10 (1), 25/02/10 (1) and 27/02/10 (6). These have central depressions on their top surfaces making them concave. The depressions were made of well molten slag as they are solid, smooth to sandpaper rough in texture with few small rounded undulations. There are no major protrusions found in these depressions but in the few instances where small to medium protrusions are present they are all smooth and rounded. These depressions are often associated with slag cakes that solidified at the bottom of a smithing hearth whereby the slag in the hottest part of the hearth (close to the air inlet – often just above the accumulating slag) was molten for a longer period of time. In most cases the central depression only covers about half of the top surface area and the slag surrounding this depression is more agitated and rougher in texture with small protrusions of material (similar to the other slag cakes described above). However, the depressions on the fragments from locations 02/02/10 (8), 21/02/10 (1) and the largest from 17/02/10 (6) dominate almost their entire top surfaces creating a smooth slightly undulated convex surface.

The bottom surfaces of the slag cakes are all rounded (convex) but vary slightly in texture. The majority (from locations 02/02/10 (8), 03/02/10 (1), 05/02/10 (5), 09/02/10 (5), 12/02/10 (3), 17/02/10 (1) (5) (6), 21/02/10 (1) (9), 27/02/10 (6)) have rough textured bases sometimes dominated by charcoal impressions up to 30mm in size but most below 15mm.

These charcoal impressions are sometimes quite deep creating angular voids. Good examples are found in locations 05/02/10 (5) and 09/02/10 (5) and in some cases there are remains of charcoal in these voids. In between these impressions are small to medium protrusions of material which make the surfaces uneven and medium to rough in texture. Most of these are rounded but in some cases they are broken and sharp. The fragment from 17/02/10 (5) and the largest fragment from 17/02/10 (6) have smaller charcoal imprints on their undersides (mostly <5mm). These are numerous and dominate the surfaces suggesting that the base of the hearths were layered with charcoal fines. The fragments from 03/02/10 (6) (14) and 25/02/10 (1) also differ as they have undulated bottom surfaces (similar to tap slag). These are medium rough in texture as they have some very small sharp protrusions but mainly because they are covered with some small quartz or stone inclusions (most <5mm). One of the fragments from 03/02/10 (1) and the three smallest from 17/02/10 (6) have fully sandy/silty undersides. These are dominated by remains of soil or dirt with small quartz or stone inclusions (1-6mm in size) still adhering to the surfaces. They are medium sandpaper rough in texture and sometimes friable in nature. The surfaces are very even with very few or no projections of material. The silty material covering the bases varies in shades of orangey-yellowy-brown and grey and could possibly be remains of a clay lining. It is likely that these fragments solidified on compacted soil or that the base of the hearths were lined with clay. Most bases have some small quartz inclusions adhering to them (mainly <5mm).

Most of the intact surfaces are relatively solid with very few spherical or globular voids (mainly <8mm). The few exceptions are fragments with broken projections (good examples are found in locations 05/02/10 (5), 17/02/10 (6) and 25/02/10 (1)) which reveal small spherical porosity beneath the surfaces. As most of the type 1 smithing slag cakes have at least one edge broken a good cross section of the slags can be seen. These reveal that they vary in porosity. The fragments from locations 03/02/10 (1) (14), 12/02/10 (3), 17/02/10 (1) (6), 21/02/10 (1) (9) and 27/02/10 (6) are all solid to semi-porous with no to few spherical and globular voids (sometimes irregular) up to 30mm but mainly <10mm in size. The fragments from 21/02/10 (1) also have a few elongated/flattened voids (horizontally from their surfaces) up to 24mm in length. The fragments from 02/02/10) (8), 03/02/10 (6), 05/02/10 (5), 09/02/10 (5), 17/02/10 (5) and 25/02/10 (1) on the other hand are more porous (semi porous to porous) with a greater percentage of spherical and globular voids (sometimes irregular) up to 10mm but mostly <5mm in size. The porosity in all slag cakes/fragments seems to be randomly distributed throughout their thickness and there are no major concentrations.

Of special interest are the slag cakes/fragments from locations 17/02/10 (1) (5) (6). These have medium to large light to mid grey patches on their surfaces. These patches do not appear to be surface based (ie. soil staining or corrosion) but look to be part of the slag. This suggests that some type of foreign material melted and fused into the slag. The grey fused material seems to be geological and could be either quartz or lime/sandstone. This may be evidence for the use of a flux (sand) during the smithing process. Indeed the fragment from 17/02/10 (1) has a large quartz inclusion on its bottom surface up to 40mm in size while some of the medium sized fragments from 17/02/10 (6) also have larger quartz inclusions on their top surfaces up to 12mm in size. This may support the theory of the addition of a flux but the possibility that the quartz accidently broke off the hearth wall cannot be ruled out.

Approximately half of the slag cakes/fragments are magnetic. The fragments from 03/02/10 (6) (14), 09/02/10 (5) and 17/02/10 (6) have magnetic patches. These magnetic areas are probably richer in metallic iron than the other parts of the slags and they are often of an orangey-yellowy-brown or dark brownish-red colour which may be surface corrosion. The fragments from locations 12/02/10 (3) and 21/02/10 (9) are heavily magnetic on the majority of their surface area meaning that these fragment must contain more metallic iron. The fact that many of these slag cakes/fragments are at least partly magnetic supports the idea that they were smithing waste.

02/02/10 (8)

01/02/10 (1)

03/02/10 (1)

03/02/10 (6)

03/02/10 (14)

05/02/10 (5)

09/02/10 (5)


12/02/10 (3)

17/02/10 (1)

17/02/10 (5)

17/02/10 (6)

17/02/10 (6)

21/02/10 (1)

21/02/10 (9)

25/02/10 (1)

Appendix C.3.2 – SS2

Characteristic features	Small amorphous lumps (some broken), orangey-brown colour, most magnetic
Size range	From 36 to 87mm in maximum length but most <60mm maximum length
Locations in which found	01/02/10 (8), 02/02/10) (8), 08/02/10 (9), 12/02/10 (1) (3) (6), 17/02/10 (1), 21/02/10 (1) (4) (5) (9), 24/02/10 (2), 25/02/10 (2) (3)

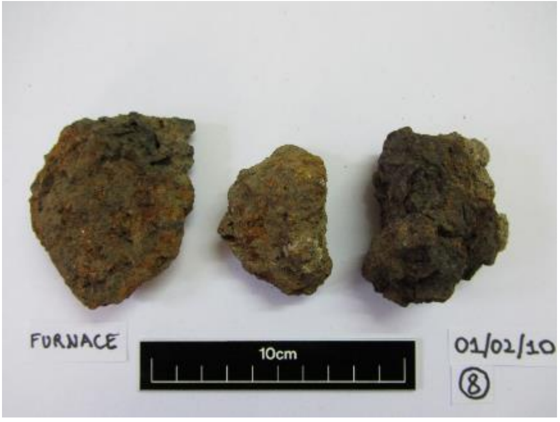
Several complete lumps and fragments of type 2 smithing slag were recovered. Their major characteristic features are their amorphous shape, dominant orangey-brown colour and the fact that most are magnetic. Due to their amorphous shape they are often difficult to identify as smithing waste meaning that some may have been characterised as furnace slag. Nevertheless more obvious examples of this type were found in locations 01/02/10 (8), 02/02/10) (8), 08/02/10 (9), 12/02/10 (1) (3) (6), 17/02/10 (1), 21/02/10 (1) (4) (5) (9), 24/02/10 (2) and 25/02/10 (2) (3).

The slag fragments and lumps vary slightly in size from 36 to 87mm in maximum length but the majority are quite small <60mm in maximum length. The majority of the slag lumps are complete or almost complete with the exception of a few fragments found in locations 12/02/10 (1) (6), 21/02/10 (9) and 24/02/10 (2) which have some broken edges. These broken edges are most often quite small suggesting that the original size of these fragments would not have been much larger.

The majority of the type 2 smithing slag is dark grey/purple or dark greyish blue in colour. However, the lumps from 21/02/10 (4) and (5) are light grey which could be due to a greater percentage of ash making their composition. The slag lumps are mostly dominated by patches varying in shades of dark orangey-brown and brownish-red. This may be due to soil staining but is most likely oxidisation (corrosion) of the surface. The surfaces of these small lumps are usually medium rough in texture with small rounded protrusions of material (some protrusions are a bit sharper). In addition, many also have medium to coarse sandpaper rough textures with very small protrusions of material. The coloured patches (corrosion layers) are also typically low to medium sandpaper rough. The broken fragments can be medium to rough in texture as the fractures have left small, sharp, angular projections. Most slag lumps found in locations 01/02/10 (8), 02/02/10) (8), 08/02/10 (9), 12/02/10 (1) (3) (6), 17/02/10 (1), 21/02/10 (4), 24/02/10 (2) and 25/02/10 (2) (3) also have small charcoal impressions on their surfaces. These are up to 25mm in size but the majority are <15mm in size (on the smaller lumps most impressions are <6mm). These are usually faint, shallow imprints recognisable by their usually angular (rectangular) shape and linear striations (imprints of the wood grain).

Most of the complete lumps of slag are solid with no to very few small spherical or globular voids <8mm in size (most <2mm). These small solid lumps are found in locations 02/02/10 (8), 12/02/10 (3), 21/02/10 (5) and 25/02/10 (2) (3). The lumps found in locations 08/02/10 (9), 17/02/10 (1), 21/02/10 (1) (4) (9) and 24/02/10 (2) are low to semi-porous with more globular and spherical voids up to 10mm in size but mostly <6mm. The broken fragments from 12/02/10 (1) (6) are semi-porous to porous with globular and spherical voids <8mm in size. The voids do not seem to concentrate in any specific location but are randomly spread throughout the thickness of the slags and on the surfaces. It is possible that some of the complete slag lumps have greater porosity beneath the surface but this cannot be ascertained due to their intact nature.

All slag lumps are heavily magnetic on their whole surface area suggesting a high metallic iron content. The two exceptions are found in locations 21/02/10 (1) and (4) which are of low and medium magnetism respectively. There are also a few fragments from 12/02/10 (1) and 21/02/10 (9) that are not magnetic but their general appearance fits with the other fragments of this type. Of special interest are a few fragments from 12/02/10 (1) which appear to have small remains of charcoal on their surfaces as well as small flakes of material which look like hammerscale. This supports the idea that these fragments and lumps resulted from the smithing process.



08/02/10 (9)

12/02/10 (3)

12/02/10 (6)

12/02/10 (6)

12/02/10 (1)

12/02/10 (1)

12/02/10 (1)

21/02/10 (1)

21/02/10 (5)

21/02/10 (9)

25/02/10 (2)

25/02/10 (3)

Appendix C.3.3 – SS3

Characteristic features	Thin, flat on one side and slaggy or more agitated on the other
Size range	From the smallest fragment 22mm in maximum length and 9mm in thickness to the largest 70mm in length, 46mm in width and 13mm in thickness. Some of the larger fragments are up to 17mm thick.
Locations in which found	02/02/10) (8), 03/02/10 (15), 05/02/10 (3), 08/02/10 (1) (4), 12/02/10 (1), 18/02/10 (4)

Very few slag fragments of this type were recovered. Their main defining characteristic features are their thin profile and the fact that they all have one flattened side and one more agitated slaggy side. Fragments of this type were found in locations 02/02/10) (8), 03/02/10 (15), 05/02/10 (3), 08/02/10 (1) (4), 12/02/10 (1) and 18/02/10 (4). The majority of the fragments are broken with fractures on the majority of their sides meaning that they would originally have been much larger. They vary in size from the smallest fragment 22mm in maximum length and 9mm in thickness to the largest 70mm in length, 46mm in width and 13mm in thickness. Some of the larger fragments are up to 17mm thick.

All fragments are dark grey (sometime purplish) in colour with patches varying in shades of dark brownish-orange and dark brownish-red. The fragment from 12/02/10 (1) is dominated by dark reddish-purple and dark orangey brown patches. These may be soil staining but is most likely corrosion of the parts with greater metallic iron content. The fragments from 05/02/10 (3), 08/02/10 (1) (4), 12/02/10 (1) and 18/02/10 (4) are all very similar (fragments from 02/02/10 (8) and 03/02/10 (15) will be discussed separately). They all have one very flat side usually smooth to the touch with no or very few small flattened protrusions. The flat sides on the fragments from 05/02/10 (3) and 12/02/10 (1) are coarse sandpaper rough with many very small sharp protrusions of material. On both of these fragments it appears that the coloured patches add to the sandpaper roughness of the surface. All of the fragments from 05/02/10 (3), 08/02/10 (1) (4), 12/02/10 (1) and 18/02/10 (4) also have similar reverse sides. These are more agitated than the flat side with well-rounded very small to small protrusions of molten slag. These sides are all low to medium rough in texture but some of the fragments from 08/02/10 (1) and 18/02/10 (4) have some broken protrusions which make their surfaces slightly sharper to the touch. These sides may also have a few small charcoal impressions (<6mm) but these are very faint and shallow so they cannot be positively identified. These fragments are characteristic of smithing flats. The raw iron bloom is rarely fully homogenous and contains a lot of slag as well as being covered in layers of slag which need to be removed by smithing. As the hammer strikes the bloom these slag layers are flattened by the blow on one side and due to their brittle nature usually flake off the consolidating iron. They are often identified as the product of primary smithing whereby the raw bloom is consolidated into rough iron bars. This would prove that the blooms were indeed smithed on site.

The fragments from 05/02/10 (3), 08/02/10 (1) (4), 12/02/10 (1) and 18/02/10 (4) are all solid to semi-porous. The voids are mainly spherical or globular in shape and are <5mm in size. The flat sides on the fragments from 08/02/10 (4) and 18/02/10 (4) are reasonably solid with very few small voids but the other fragments have greater porosity on these flat surfaces. Most of the uneven agitated slaggy sides are solid to low porosity but the fragment from 18/02/10 (4) is partially broken revealing many very small voids underneath the surface. The broken edges also reveal very small voids on most fragments. These voids do not appear to concentrate in any particular area but are randomly spread throughout the fragments. All of the fragments are also magnetic; fragments from 08/02/10 (1) (4), 12/02/10 (1) and 18/02/10 (4) are low in magnetism or only magnetic in parts while the fragment from 05/02/10 (3) is highly magnetic. This means that they all must contain some metallic iron and strengthens the idea that they are smithing waste.

05/02/10 (3)

12/02/10 (1)


18/02/10 (4)


08/02/10 (1)


08/02/10 (4)

The fragments from 02/02/10 (8) and 03/02/10 (15) are slightly different than those discussed above. They tend to be thicker and their flat sides are not as even and plano with changes in angles and more small projections. These sides do tend to be relatively smooth but the fragments from 03/02/10 (15) are rougher being medium rough and coarse sandpaper rough with many very small and small sharp projections. Their other sides are similar to the fragments above with many small rounded projections of well-molten slag but are for the most part slightly rougher. Some of these surfaces have partially chipped off the fragments from 03/02/10 (15) leaving sharp angular projections. The slags from 02/02/10 (8) are solid to semi-porous with two fragments being solid and the third being semi-porous. The fragments from 03/02/10 (15) are semi-porous to porous. This is partially due to the fact that the surfaces are partially broken revealing greater porosity beneath. All voids are spherical or globular (except a few in the 03/02/10 (15) examples that are irregular in shape) and <3mm in size. All fragments are highly magnetic except a few small one from 03/02/10 (15) that are medium magnetic. This supports the idea that they are smithing waste, however, their size and shape suggests that they are not smithing flats like the other fragments discussed above. It is possible that they are either more iron rich slag fragments that became detached from the bloom while smithing or perhaps they are just iron rich slag which solidified against a hard flat surface.

02/02/10 (8)


03/02/10 (15)

Appendix C.4 – Furnace Lining/Wall

Many furnace lining fragments were recovered during the 2010 Pioneering Metallurgy Project. Several types of furnace wall could be identified and this section will deal with their descriptions. All furnace material is fragmentary with few surviving original surfaces meaning that many are non-diagnostic. However, a few are better preserved with some diagnostic features allowing the diameter of the furnaces to be estimated from their surviving curvature. Table 1 below shows the weight in grams and general dimensions of the different types of furnace wall found in each location. Photographs relate to the text directly preceding them.

Table 1 - Weight in grams and general dimensions (mm) of the different types of furnace wall in each location.

Location	Type (FW)	Weight	No	Fabric	Inclusions	Length	Height	Width	Est. dia-meter	Notes
25/01/10 (3)	?(2)	124	1	C	Quartz <5 + pottery	66	63	35	?	No original surfaces
25/01/10 (6)	3	370	1	M	Quartz <3 up to 11	176	88	23	none	Straight rim frag – vit
	?(2)	1784	6	L-M	Quartz <3mm	109 140	42 59	28 60	?	Curved + vit
	?(2)	687	lot	L-M	Quartz <3mm	<90			?	2 vit – rest no original surf
26/01/10 (8)	?(2)	220	3	M	Quartz <3mm	<65			?	Heavy vit
28/01/10 (1)	?(1)	37	1	M-C	Quartz	64	30	34	?	vit
28/01/10 (5)	1	1290	1	M-C	Quartz <5 up to 8	161	120	60b 38t	?	vit
	?(3)	900	3	C	Quartz <5mm	<118			?	Heavy vit – no ext surf
	?(2)	290	2	L-M	Quartz <2mm	<80			?	Vit – no original surf
29/01/10 (1)	3	2370	1	VC	Quartz <10mm	267	175	58	?	straight wall – vit – flat side (base?)
	2	963	1	VC	Quartz <10 - charcoal	?	?	?	?	Vit + curved – coil built 40-50mm wide
	2?	1579	sev	VC	Quartz <10mm		68	90	?	Coils? – no vit – lg looks like rim?
	?(3)	1150	4	C-VC	Quartz <4mm	<76 108	 102	 33-51	?	Vit – no ext surf
29/01/10 (2)	1?	1230	1	M-C	Quartz <4 up to 13	178	98	96b 87t	?	Vit – flat base – tuyere frag
	?	1480	1	M-C	Quartz <4 up to 13	198	124	132	?	Vit + slag – tuyere impr – shaped base
29/01/10 (3)	?(3)	610	3	C	Quartz <4 up to 10	<97			?	Heavy vit – no original surf.
29/01/10 (4)	?(4)	50	1	F	Quartz <1 organic?	64		23	?	Oxidised surfaces
29/01/10 (5)	?(4)	220	2	F	Quartz <1 organic <18 elong	<81			250	Reduced surfaces – curved
30/01/10 (1)	?(1)	210	1	M	Quartz <2mm	55	71	50	?	Fully vit

Location	Type (FW)	Weight	No	Fabric	Inclusions	Length	Height	Width	Est. dia-meter	Notes
30/01/10 (2)	?(1)	470	1	M	Quartz <2mm	91			?	Fully vit
01/02/10 (1)	?(3)	814	9	VC	Quartz <5 up to 10	<75-115	83	45	?	Vit – no ext surf
01/02/10 (2)	?(1)	295	4	C - VC	Quartz <5 up to 10	<56			?	Fully vit – no original surf.
	?(3)	4815	2	C	Quartz <5 up to 10 – organic?	161 222	138 167	31 62	?	Vit + curved
01/02/10 (3)	?(3)	100	1	C	Quartz <5mm	77			?	Vit – no original surf.
01/02/10 (4)	?(3)	240	2	C	Quartz <4mm	<84			?	Vit – no original surf.
01/02/10 (5)	?(1)	210	1	M-C	Quartz <4mm	87			?	Fully vit
	?(3)	420	1	C	Quartz <4 up to 8	104			?	Vit – no original surf.
01/02/10 (6)	?(4)	117								Pottery?
	?(2)	700	3	M	quartz	131	63	47	?	Light vit – no original surf – tuyere imp
01/02/10 (8)	1	510	4	L-M	Quartz <2 organic cereal <7	47-91	87	43-35	Ext 340	Light vit + curved – ext linear vertical imp
02/02/10 (1)	?(2)	430	2	M	Quartz <4mm	78-104			?	Vit – no original surf.
02/02/10 (4)	?(1)	106	1	M-C?	Quartz <3mm	60	52	39	?	Fully vit with adhering quartzite
02/02/10 (5)	?(3)	310	4	C	Quartz <5mm	<78			?	Vit – no original surf.
02/02/10 (6)	?(2)	331	2	C	Quartz <3 up to 5	54 97	48 86	19 36	?	Lg frag with stone in
02/02/10 (7)	?(4)	189	1	F-M	Quartz <2mm	104	82	15	?	Pottery? stone in – vertical impr
	?(3)	960	lot	C	Quartz <5mm	<60-135	96	55	?	Vit – no ext surf
02/02/10 (8)	1?	1380	10	L-M	Quartz <3 organic <12 thin	<89-126	93	17 27	250-280	Light vit + curved
03/02/10 (1)	?(2)	21	1	M-C	Quartz	45	36	12	?	vit
03/02/10 (3)	?(2)	562	1	C	Quartz <2 up to 10	154	101	72	?	Vit – tuyere frag
03/02/10 (4)	?(2)	2270	14	M	Quartz <2 up to 5	36-177			?	Vit – no original surf.
03/02/10 (6)	1?	2020	2	M	Quartz <3 up to 16	148	122	46-74	Ext 340	Vit + curved
	1?	240	2	F-L	Quartz <1 organic cereal <6	79 92	40 61	39 47	?	Curved – abraded surf
	?(1)	390	1	?	?	131			?	Fully vit
	?(2)	232	7	M	Quartz <3 up to 5	<59			?	No original surfaces
03/02/10 (7)	?(2)	523	6	M-C	Quartz <3mm	<120	?	?		vit
03/02/10 (9)	1?	710	1	M	Quartz <1 up to 5 - organic	84	43	33	?	Light vit + curved – int vertical impressions
	1?		1	M	Quartz up to 8	122	116	43	?	curved – ext vertical impressions int surf missing
	1	1290	11	L	Quartz <2 organic cereal	47-110	27-75	22-35	Ext 400	Vit + curved – vertical impressions
	?(3)	680	3	C	Quartz <5 up to 13	60-165	70	42	<400	Vit + curved – no ext surf.

Location	Type (FW)	Weight	No	Fabric	Inclusions	Length	Height	Width	Est. dia-meter	Notes
03/02/10 (10)	1?	231	1	M	Quartz <1 up to 5 - organic	92	68	40	?	Light vit + curved – int vertical impressions
03/02/10 (11)	1	643	1	L-M	Quartz <2 up to 6 – organic	136	98	45	?	Curved (rim or base) – fine vit
	1?	1210	11	M	Quartz <2 up to 7 + organic?	36-106	30-80	32-37 up to 55	?	Light vit
	?(2)	434	1	M-C	Quartz <7mm	135	100	47	?	vit
03/02/10 (12)	?(2)	250	1	M	Quartz <2 up to 8	84	70	45	?	No int surf.
03/02/10 (13)	1	4823	7	M	Quartz <2mm	84-143-215	53-65-120	70b 55t 77b 40t 80b 25t	380-400	Light vit + curved (base frags) – int + ext vertical imp.
	1	2710	11	M	Quartz <2mm	62-151	48-93	18-45	380-400	Light vit + curved – int vertical imp.
	?(3)	500	1	C-VC	Quartz <3mm	102	75	55	?	Vit + slag – no original surf.
03/02/10 (14)	1	1876	3	M	Quartz <3mm	116 136	100 81	55b 27t 60b 38t	400	Light vit – base frags – int + ext diagonal imp.
	1	2426	13	M	Quartz <3mm	54-166	60-70	20-23	400	Light vit + curved (body frags) – int vertical imp – ext thin striations
	?(3)	1210	4	C-VC	Quartz <3 up to 6	35-163	116	57	?	Heavy vit
03/02/10 (15)	1	2670	4	M	Quartz <5mm	109 112 124 120	75 120 48 71	65b 38t 72b 33t 61b 45t 75b 45t	360	Vit + curved (base frag) - int + ext vertical impressions
	1	3185	10	M	Quartz <3mm	95-180	81-99	21-50	400	Light vit + curved (body frag) - int vertical imp – ext linear striations
	1?	790	3	M	Quartz <2mm	91 145	65 38	39 40	380	Light vit + curved – ext angled linear imp
	?(3)	2540	11	C-VC	Quartz <5 up to 13	36-164	125	50	400+	Heavy vit – 1 curved – no ext surf
05/02/10 (1)	1	1350	1	M-C	Quartz <2 up to 3 organic?	?	115	83b 40t	240-300	Light vit + curved (body frag) - int vertical impressions
	1	2530	12	M	Quartz <2mm	63-157	45-87	18-31	400	Light vit + curved – int vertical imp.
	?(3)	2160	14	C	Quartz <5 up to 9	45-175		<58	?	Heavy vit – no original surf.
05/02/10 (2)	3	2010	3	M	Quartz <2 up to 14 charcoal	165 163	73 128	58 48-62	?	Straight – rim frags rounded edge – no vit
	?(2)	340	1	M-C	Quartz <5 up to 8	89	87	56	?	Heavy vit – no ext surf
05/02/10 (3)	1?	1180	1	M-C	Quartz <3 up to 5 organic?	?	?	45b? 38t	?	Vit + curved – base maybe missing
	?(4)	552	2	F-L	Few quartz – lots org.	<100	?	20	?	Maybe pottery?
	1?	396	2	M-C	Quartz <3 up to 5 organic?	<120	?	?	?	Vit – v. frag.
05/02/10 (4)	3	779	1	M	Quartz <2 up to 3 organic?	?	?	30	?	Vit straight wall – mid frag
	1?	1496	3	M-C	Quartz <2 up to 3 organic?	<120	?	?	?	Light vit – v. frag.

Location	Type (FW)	Weight	No	Fabric	Inclusions	Length	Height	Width	Est. diameter	Notes
	1?	251	1	F-L	Few quartz – organic cereal	?	?	?	240-300	Light vit + curved – tapering thickness
05/02/10 (6)	?(2)	370	6	M	Quartz <3 up to 10	<77			?	Abraded small frags – no vit
	?(2)	60	1	F	Quartz < 1 organic cereal	50	27	50	?	Small frag - abraded
05/02/10 (7)	3	2429	3	M-C	Quartz <3 up to 5 Organic?	95-191	87-129	34-43-53b 33t	?	Vit –straight wall – 1 has flat edge – 1 rim – finger marks?
	1	260	1	F	Quartz <1 up to 4 organic cereal	99	63	50b 25t	280-300	Base frag – light vit + curved
	1	640	1	M	Quartz <3mm	124	120	61b 45t	Ext 400	Base frag – vit + curved – tuyere frag
	1?	890	2	M	Quartz <3mm	147 58	108 91	53 46	?	Vit + slightly curved
06/02/10 (2)	?(3)	522	sev	VC	Quartz <3 up to 11	108	80	46	?	Sm frags – vit + no ext surf.- iron prills on vit
	?(1)	120	1	M?	Quartz <2mm	85			?	Fully vit
08/02/10 (1)	1	621	2	F-L	Quartz <4 – organic cereal	126 168	68 88	22 20	260-340	Rim frags – light vit + curved – int vertical imp.
	1?	1610	6	M-C	Quartz <3 up to 8	46-117	203	69	?	Vit + curved – 1 poss base and tuyere imp
	3?	2040	4	M	Quartz <3 up to 7	74-128	103	77	?	Straight – friable – no int surf.
	?(1)	2940	2	?	quartz	<229			?	Fully vit amorphous frag
	?(1)	130	4	C?	Quartz <3mm	<51			?	Fully vit frags
	?(3)	3990	8	C -VC	Quartz <3 up to 5	65 203	184	110	?	Heavy vit – chalk/lim/sandstone inclusions
08/02/10 (2)	?(3)	440	4	C -VC	Quartz <4mm	<72 111	88	42	?	1 heavy vit – rest no original surf
	1?	60	1	F	Quartz <3 organic cereal	80	48	22	Ext 360	Light vit + curved
08/02/10 (3)	1	1390	1	L-M	Quartz <3 – organic cereal	?	?	62b 41t	300-350	Vit + curved with flat base
	1?	390	1	M	Quartz <3mm	117	105	37	?	Heavy vit
	?(2)	350	1	M	Quartz <2mm	95	98	43	?	reduced
08/02/10 (4)	1	1610	1	L-M	Quartz <3 – organic cereal	240	130	52b 17t	360	Fine vit + curved base
	?(3)	963	1	C-VC	Quartz <3 up to 6	135	134	56	?	Heavy vit + curved
	?(1)	975	sev	C-VC	Quartz <3 – organic	<120	?	?	?	Vit – lg fully vit + magnetic patch
08/02/10 (5)	?(1)	1380	1	M	Quartz <3mm	191	160	90	?	Fully vit
08/02/10 (8)	1	466	1	L	Quartz – organic cereal	?	104	32b 20t	300-320	Light vit + curved base
	1?	125	1	L	Quartz – organic cereal	?	?	?	300-320	Light vit + curved – frag
	1?	641	sev	M	Quartz – lots orga	?	?	?	?	Light vit – fragmentary

Location	Type (FW)	Weight	No	Fabric	Inclusions	Length	Height	Width	Est. dia-meter	Notes
	2?	651	Se v	C-VC	Quartz <10mm	?	?	?	?	1 frag evidence of coil built 35-40mm
08/02/10 (9)	1	542	1	L	Quartz – organic cereal	?	92	47b 21t	300-320	Light vit + curved base
	1?	1678	2	L	Quartz – organic cereal	?	?	?	?	Light vit – 1 curved – fragmentary
	2	5570	2	C-VC	Quartz <10mm – organic	155 268	253 222	80 73	>500	Heavy vit + curved – coil built 35-45mm
	2?	206	sev	C-VC	Quartz <10mm	<120	?	?	?	Heavy vit – fragmentary
08/02/10 (10)	?(2)	875	sev	M	Quartz – lot organic	?	?	?	?	Vit - fragmentary
	?(3)	30	1	C-VC	Quartz <4 up to 8	56			?	Vit - fragmentary
09/02/10 (1)	?(3)	1505	3	VC	Quartz <5 Up to 17	<200	?	?	?	Vit – fragmentary – no original ext surf.
09/02/10 (2)	1?	345	5	M	Quartz <2 up to 5	<90	?	13-22	?	Light vit – v fragmentary
	?(3)	470	1	C-VC	Quartz <3 up to 7	166	88	32	<300	Heavy vit – no ext surf
	?(2)	830	1	M	Quartz <2 up to 6	124	144	47	Ext 180	No vit …abraded?
	?(2)	2520	1	M	Quartz <3 up to 6	215	237	39	360	Vit + curved – abraded ext surf
09/02/10 (5)	?(3)	240	2	VC	Quartz <5 Up to 13	55 70	?	?	?	Vit - fragmentary
09/02/10 (6)	1?	2100	5	M	Quartz <3 up to 9	91-144	64-144	34-75	?	Vit + slight curve
	1?	256	1	L-M	Few quartz – organic cereal	<60	?	?	?	Light vit - fragmentary
	?(1)	534	2	M-C	Quartz <2	<100	?	?	?	Heavy vit - fragmentary
	?(2)	179	2	M	Quartz <2 - organic	?	?	?	?	1 vit – fragmentary - 1 magnetic patch
10/02/10 (1)	?(2)	499	sev	F - silty	V few quartz – organic?	101 (largest)	94	47	?	Light vit - fragmentary
	?(1)	226	2	C	Quartz <2 up to 9	<60	?	?	?	Fully vit - fragmentary
10/02/10 (2)	?(2)	67	2	?	?	?	?	?	?	Small vitrified wall + slag – v fragmentary
11/02/10 (1)	1?	370	3	M	Quartz <3 up to 7 organic?	65-90	46-75	30-30	Ext 380	Light vit + curved – int linear vertical imp.
11/02/10 (2)	?(3)	100	1	C-VC	Quartz <4 up to 9	77	54	30	?	Heavy vit - fragmentary
	?(2)	60	1	M	Quartz <2mm	59			?	Fragmentary – no original surf.
11/02/10 (5)	?(3)	2760	7	C	Quartz <5 up to 12	37-191	115	80	Ext >500?	Heavy vit + slight curve - fragmentary
	1	350	2	F-M	Quartz <2 organic cereal?	50 77	44 82	22 35-60	?	Light vit – possible base – int vertical linear imp
	1?	30	1	F	Quartz <2 organic cereal	58	29		~300	Light vit + curved
11/02/10 (6)	1	6821	5	L-M M	Quartz <3 up to 13	123 sm 236 lg	72 189	41 80	?	Vit + curved – 1-2 base frags + 1 with stone embedded
	1?	1616	sev	L-M M	Quartz <3 up to 8	<90 114	? 83	20-30 50b 30t	?	Vit + fragmentary – 1 base frag

Location	Type (FW)	Weight	No	Fabric	Inclusions	Length	Height	Width	Est. dia-meter	Notes
12/02/10 (1)	1	1661	3	F-L	Few quartz lot organic – slag?	?	80-100	36-44b 16-23t	280-360	Light vit + curved - bases
	1?	617	sev	F-L	Few quartz lot organic – slag?	?	?	16-23	280-360	Light vit + curved – fragmentary – brush striations
	?(2)	3860	1	L sandy	Quartz – organic – slag?	187	211	93	?	Lg non-vit frag …..?
	?(2)	386	sev	M	Quartz <2 – slag?	<40	?	?	?	Very frag no original surf – 1 vit
12/02/10 (2)	1?	255	2	F-L	Quartz – organic – slag?	<130	?	10-16	?	Light vit + curved – white organic inclusions in matrix (like crucibles) – brush striations
	?(4)	229	sev	F-L	Few quartz lot organic – slag?	<80	?	9-12	?	Layer of plaster?/ burnish? Upto 2mm… Pot?
12/02/10 (3)	?(2)	286	1	L-M	Quartz <1mm	100	?	32	?	Not vitrified????
12/02/10 (4)	?(2)	399	2	L-M	Quartz – organic	?	?	33-37b taper	?	Bases? – abraded – no vit
12/02/10 (5)	?(2)	40	1	F-M	Quartz <2mm	54	33	20	?	V fragmentary – no original surf.
12/02/10 (6)	?(4)	57	1	F-L	Few quartz lot organic – slag?	53	?	19	?	Light Vit or plaster/ burnish? – frag
	?(2)	1850	6	L	Quartz <1 up to 5	55-135	36-125	27-76	?	1 reduced side - fragmentary
12/02/10 (7)	1?	210	3	M	Quartz <2 – organic – slag?	?	?	50-60b	?	1 base fragmentary - Light vit – rest v frag <50mm
12/02/10 (8)	1?	612	3	M	Quartz <2 – organic – slag?	?	?	50-60b	?	1 base fragmentary - Light vit – rest v frag <50mm
	1?		1	M	Quartz <2 – organic – slag?	?	?	40 (body) 27 top	?	1 rim frag – light vit – 3 horizontal striations on back
13/02/10 (1)	1	646	1	M-C	Quartz <5mm	?	103	63b 36t	300	Light vit + curved – vertical striation int ext
	1?		1	M-C	Quartz <5mm – organic?	<40	?	17	?	Light vit – frag – vertical striations int – ext abraded
	?(3)	2150	4	C-VC	Quartz <5 up to 15	55-169	192	83	?	Possible bases – heavy vit – no ext surf – tuyere adhering
13/02/10 (2)	?	22	1	?	?	?	?	?	?	
	?(3)	590	1	C-VC	Quartz <5 up to 10	56 107	64 104	38 48	?	Heavy vit + slight curve – fragmentary
13/02/10 (3)	1	340	1	M	Quartz <2 up to 10	112	85	30-41	?	Vit + slight curve – ext linear vertical imp
13/02/10 (4)	?	1030	1							
13/02/10 (11)	?(3)	120	4	C-VC	Quartz <4mm	36-60			?	Light vit – no ext surf
13/02/10 (12)	1?	130	1	L	Quartz <2 organic cereal	101	54	30	?	Light vit + curved
13/02/10 (13)	1?	124	1	C-VC	Quartz <5 up to 15	78	?	27	?	Light vit + curved – ext surface abraded
13/02/10 (15)	1?	469	sev	C-VC	Quartz <5 up to 15	?	85	55b	?	1 base frag - no original surfaces – rest v frag – light vit
	1?	121	1	C	Quartz <5 up to 15 – organic	?	90	21	?	Light vit + curved – ext abraded

Location	Type (FW)	Weight	No	Fabric	Inclusions	Length	Height	Width	Est. dia-meter	Notes
15/02/10 (1)	?(2)	130	1	L-M	Quartz <2 organic cereal?	99	53	39	?	Reduced one side – abraded + fragmentary
15/02/10 (2)	?(3)	760	4	C	Quartz <4 up to 8	50-133	109	56	?	Heavy vit – no ext surf
	1	400	2	L-M	Quartz <2 organic cereal	94 78	42 75	28 27-45	360	Light vit + curved – ext angled linear imp
15/02/10 (3)	?(2)	128	sev	M-C	Quartz <4mm	<80	?	?	?	Light vit – v frag
15/02/10 (4)	?(2)	305	1	M-C	Quartz <4mm	92	43	53	?	Light vit – no original surfaces
16/02/10 (1)	1	1100	1	M	Quartz <3mm	147	100	50	?	Thin vit – curved – vertical int ext striations – base is broken
	1	950	1	L-M	Quartz <2 organic cereal	165	103	59b 35t	360	Base frag – light vit + curved – int + ver vertical linear imp
	1	1090	4	L-M	Quartz <2 organic cereal	87-98	60-105	35-32	360	Light vit + curved – int vertical linear imp
	?(3)	750	4	C-VC	Quartz <4 up to 17	45-127	118	43	?	Heavy vit – no ext surf
16/02/10 (2)	1?	1570	15	M-C	Quartz <3 up to 7	36-158	25-122	18-35	?	Some heavy some light vit + curved – abraded frag
	?(1)	513	3	M-C?	Quartz <3 up to 6	<96	?	?	?	Fully vit
16/02/10 (5)	1?	615	sev	M	Quartz <4 up to 6	? 106 (frag)	?	40-50	?	Vit - 1 frag curved – ext surfaces missing – most frag and fully vit
	?(3)	1782	4	C-VC	Quartz <4 up to 10	74-150	48-161	34-86	?	Heavy vit – no ext surf
16/02/10 (6)	?(2)	120	2	L	Quartz <1 few	58 72	38 43	22 40	Ext 380	Light vit + curved - fragmentary
	1	390	1	F	Quartz <1 organic cereal	145	113	24	300	Light vit + curved – int angled linear imp
17/02/10 (1)	?(4)	173	1	F	Quartz – organic?	111	70	24	?	Slightly curved – pot?
	3	3580	4	F-L	Quartz <2 - organic	67-262	34-226	29-80	?	Vit – straight wall – no curvature
	?(1)	90	1	M?	Quartz <2mm	56			?	Fully vit
17/02/10 (2)	?(2)	60	1	M	Quartz <2mm	67	34	26	?	Vit - fragmentary
	?(1)	160	5	?	Quartz <5mm	<53			?	Fully vit - fragmentary
	?(3)	1010	2	C-VC	Quartz <4 up to 7	133-150	122-115	42-37	400+?	Vit – abraded ext surf
17/02/10 (3)	?(2)	624	1	M	Quartz <4mm	115	60	64	>500	Quite abraded – but likely furnace base.
	?(3)	140	1	C-VC	Quartz <4 up to 7	80	60	44	?	Vit – abraded surf. – rounded edges – may be coil
	3	480	1	M	Quartz <3 up to 9	145	89	41	?	Vit – straight?
17/02/10 (4)	3?	73	1	L	Quartz <1 – organic?	58	?	34	?	V frag – inner layer vit
17/02/10 (6)	3?	812	3	L	Quartz <1 – organic?	74-140	?	42-65	?	Vit (inner layer) – no curvature – 2 frags may be bricks (1 vit)
	?(2)	158	5	?	Prob same as above	?	?	?	?	Almost fully vit

Location	Type (FW)	Weight	No	Fabric	Inclusions	Length	Height	Width	Est. dia-meter	Notes
18/02/10 (1)	3?	438	1	M	Quartz <2 – charcoal?	145	?	40	?	Vit - No curvature – no original ext surfa
	?(2)	90	1	M	Quartz <3 up to 5	76	46	31	?	No vit – no curvature – abraded
	?(1)	30	1	?	quartz	46			?	Fully vit
18/02/10 (2)	1?	682	1	M-C	Quartz <3 up to 11	133	?	62 tap. to 35	?	Vit – frag – no original ext surfaces
	?(2)	310	2	M-C	Quartz <3 up to 9	65 88	64 78	40 45	?	Heavy vit – v fragmentary
18/02/10 (3)	1?	1370	3	M	Quartz <2 up to 17	108- 115	76- 152	58- 57	?	Heavy vit + curved – tuyere frag?
	1	2140	2	F-L	Quartz <1 organic cereal	245 171	50 163	58b 50t 55b 35t	360-380	Base frags – light vit + curved – ext vertical linear imp.
	1	400	1	F-L	Quartz <1 organic cereal	130	91	22	320 distorte d	Rim rounded frag – light vit + curved – ext angled linear imp
	?(2)	3340	1	M	Quartz <2 up to 6	202	191	103	?	Heavy vit – abraded ext surf.
18/02/10 (4)	1	2130	5	M	Quartz <3 up to 6	43- 197	153	74b 40t	Ext >400	Light vit + curved – 1 flat base + no flare
	1	830	4	F-L	Quartz <1 organic cereal	65- 109	42- 95	24- 36	360-380	Light vit + curved – ext thin angled striations
	3?	486	1	M	Quartz <2mm	142	?	50 tap to 25	?	Vit (some magnetic) – no curvature – poss rim frag – diagonal striations
18/02/10 (5)	1?	130	2	F-L	Quartz <2 organic cereal	40 91	26 48	23 27	?	Light vit + slight curve – abraded frags
	?(2)	40	1	M	Quartz <2mm	49			?	Heavy vit – abraded – no original surf.
18/02/10 (6)	1	3740	14	M-C	Quartz <4 up to 14	46- 144	132	67b 50t	Ext >400	Fragmentary – 1 base frag – no flare + curved + light vit
	1?	411	1	M	Quartz <2 up to 8	130	?	35	?	Vit – slight curve – tuyere – prob. Base – no original ext surf
	1?	877	1	M	Quartz <2	119	88	22	400	Vit + curved – large frag re-lined
	1	865	5	F-L	Quartz <1 organic cereal	95- 113	56- 49	23- 29	380	Light vit + curved – 1 rim rounded frag
18/02/10 (7)	?(3)	80	1	C	Quartz <2mm	66	55	28	?	Heavy vit – frag – no ext surf.
19/02/10 (1)	?(1)	128	3	M	Quartz <3mm	47-82	34-49	27-34	?	Mostly vitrified – v frag
19/02/10 (3)	1	1490	1	M	Quartz <3mm	163	140	50b 30t 76 w vit	?	Vit + curved – base – tuyere – magnetic vit patch
	1?	1770	8	M	Quartz <2mm	75- 86	45- 116	20- 62	?	Vit – abraded ext surf.
	1?	230	2	F-L	Quartz <1 Organic cereal	67 100	43 73	20 31	?	Light vit + curved - fragmentary
	?(2)	1830	9	M	Quartz <2mm	62- 129	137	57	?	Very abraded – no original surf.
	?(1)	770	4	M-C?	Quartz <2mm	124			?	Fully vit
	?(3)	2040	1	C	Quartz <5 up to 13	137	226	93	?	Heavy vit – abraded ext surf.
19/02/10 (4)	1	10874	6	M	Quartz <3mm	265 270 220 74	326 212 184 146	60b 20t 60b 20t 60b 20t 60b 20t	340-400	Light vit + curved – thin ext striations and lg int vertical imp

Location	Type (FW)	Weight	No	Fabric	Inclusions	Length	Height	Width	Est. dia-meter	Notes
						104 98	90 142	66b 30t 31		
	1	910	6	M	Quartz <2 up to 6	66- 104	42- 75	25- 28	340-380	Light vit + curved – int vertical imp + ext vertical thin striations
	?(3)	1350	6	C-VC	Quartz <4 up to 9	66- 135	41- 89	23- 62	?	Heavy vit – no ext surf.
	?(1)	560	1	M-C?	Quartz <4 up to 11	142	119	52	?	Fully vit
19/02/10 (5)	1	211	1	M	Quartz <3mm	90	74	38b 11t	?	Light vit + curved – int horiz striations – no ext original surf
	1	190	2	M	Quartz <2 organic?	45- 69	60- 86	21- 19	?	Light vit + slightly curved – int vertical linear imp
	1	470	4	F-L	Quartz <2 organic cereal	60- 83	29- 58	21- 40	?	Light vit + curved – int vertical linear imp
	?(1)	282	2	C-VC?	?	<70	?	?	?	Vitrified v frag – adhering magnetic slag
	?(2)	720	4	L-M	Quartz <1mm	67- 100	72	46	?	Abraded frag – no vit
	?(2)	520	1	M	Quartz <2mm	123	98	58	?	Heavy vit – abraded ext surf.
	?(3)	1260	2	C-VC	Quartz <5 up to 9	84 164	156	70-37	?	Heavy vit – abraded ext surf.
19/02/10 (6)	1	3010	2	M	Quartz <5 up to 9	184 195	101 163	64b 23t 78b 35t	350-400 ~320	Base frags – light vit + curved – thin ext vertical striations – magnetic vit patch
	1	340	1	M	Quartz <2mm	124	80	28	Ext 380	Light vit + curved – int vertical linear imp + ext vertical thin striations
	1?	130	2	F-L	Quartz <2 organic cereal	45 74	32 66	12 22	360-380	Light vit + curved
	?(2)	148	2	M	Quartz <5mm	?	?	?	?	V frag – vit – maybe 1 frag of type 1?
	?(3)	5880	5	C-VC	Quartz <4 up to 10	108- 249- 186	95- 149- 272	40- 55- 98	Ext 360	Heavy vit – no ext surf – 1 tuyere frag?
	?	1170	1	VC	Quartz <5 up to 8	174	95	113	?	Vit – bowl shaped base? – slag and magnetic vit
21/02/10 (1)	?(1)	142	2	VC?	Quartz <5 up to 16	50- 53	42	32	?	Fully vit – v frag
21/02/10 (3)	?(1/3)	1677	12	VC	Quartz <5 up to 16	50- 115	49- 91	48- 47	?	Vit – most fully vit – all frag and no original surfaces
21/02/10 (4)	?(1)	60	1	C	Quartz <3mm	59			?	Fully vit – frag
21/02/10 (7)	?(3)	1580	5	C-VC	Quartz <4 up to 10	45- 142	91	63	?	Fully vit – large frag some reduced clay
21/02/10 (9)	1?	80	1	F-L	Quartz <2 organic cereal	52	38	26	?	Light vit + curved
	?(2)	680	7	M	Quartz <2mm	37- 92			?	Amorphous fully abraded frags
	?(2)	130	2	F	Quartz <1 organic?	<63			?	Abraded frags – silty
22/02/10 (1)	?(3)	534	1	VC	Quartz <5mm	162	103	35	?	Heavy vit – parts magnetic
	?(1)	320	2	?	Quartz <3mm	<82			?	Fully vit frags

Location	Type (FW)	Weight	No	Fabric	Inclusions	Length	Height	Width	Est. dia-meter	Notes
22/02/10 (3)	?(2)	50	1	F-L	Quartz <2 organic cereal	48	38	38	?	Abraded frag – no int surf
	?(2)	90	4	M	Quartz <2mm	<57			?	Abraded frags – no original surf
	? brick	240	1	M-C	Quartz <4 up to 8	72			?	Fully reduced – flat edges – brick?
23/02/10 (1)	?(1/2)	375	4	M-C L C	Quartz Organic	<90	?	?	?	V frag – 4 diff frags
	?(1)	220	2	M	Quartz <2mm	56-77			?	Vit – amorphous abraded lumps
23/02/10 (2)	?(2)	580	2	M	Quartz <2 up to 5	98 114	64 93	37 37	?	Heavy vit - frags
23/02/10 (3)	2	648	1	M	Quartz <2mm	112	117	45	?	Heavy vit – slight curve – coils 35-40mm wide
	1?	230	1	F-L	Quartz <2 organic cereal	83	51	47	360-380	Light vit + curved – broken base frag?
	?(2)	240	2	M	Quartz <2mm	50 80	61	48	?	Vit – abraded frags
23/02/10 (4)	1	568	1	M	Quartz <3mm	?	123	65b 40t	?	Vit – base frag
	?(2)	260	1	M	Quartz <2mm	110			?	Vit – tuyere imp
23/02/10 (6)	?(2)	520	1	M	Quartz <2 up to 5	138	119	69	?	Vit – abraded ext surf
	?(3?)	530	1	C	Quartz <5mm	100			?	Fully abraded amorphous frag
23/02/10 (7)	2	1110	1	L-M	Quartz <2mm	120	154	61	?	Heavy vit – coils 40mm wide
	?(2)	50	2	M	Quartz <2mm	<38			?	Small abraded frags
23/02/10 (8)	1?	110	1	M	Quartz <2mm	79	49	26	Ext ~400	Light vit + curved – ext angled linear imp
	?(3)	350	4	C-VC	Quartz <4 up to 9	56-110			>400?	Heavy vit – no ext surf
23/02/10 (9)	4	4010	1	C	Quartz <5 up to 12	260	156	112b 73t	?	Almost complete smithing? Tuyere re-use in wall
	1?	1650	1	M	Quartz <2mm	228	154	59	?	Vit + curved – poor preservation – tuyere embedded
	1?	1560	1	M	Quartz <2mm	170	170	50	400 ext	Vit + curved base – tuyere embedded – ext abraded
	?	1400	1	M	Quartz <2mm	190	123	95	?	Mix of slag with furnace wall – tuyere – curved on bottom
23/02/10 (10)	1?	160	1	F-L	Quartz <1 organic cereal	97	58	30	Ext ~400	Light vit + curved
	?(3)	380	2	C-VC	Quartz <4 up to 12	95 103	60 73	36 41	?	Heavy vit – no ext surf
23/02/10 (11)	?(2)	670	1	M	Quartz <3 up to 17	132			?	Amorphous – no original surf
23/02/10 (12)	?(2)	13	1	M	Quartz	30	?	?	?	Vit – v frag
	?(3)	940	1	C-VC	Quartz <5 up to 12	188	85	65	?	Heavy vit + slightly curved – abraded ext surf
24/02/10 (1)	3	1250	1	C	Quartz <6mm	131	143	72 43t	?	Vit – no curve – rim frag? Rounded edge
	1	560	6	F-L	Quartz <1 organic cereal	45-75	30-73	14-23	380-400	Light vit + curved – int linear imp

Location	Type (FW)	Weight	No	Fabric	Inclusions	Length	Height	Width	Est. dia-meter	Notes
	1?	590	1	M	Quartz <2mm	139	106	52-30	Ext ~400	Light vit + curved – broken base?
	?(3)	1030	6	C-VC	Quartz <4 up to 10	85-118	48-105	26-43	?	Vit + curved – no ext surf
24/02/10 (2)	?(1)	660	4	M-C?	Quartz	57-95	?	?	?	Heavy vit (fully) – v frag
	?(2)	440	1	M-C	Quartz <3 up to 5	108	87	55	?	Vit – abraded surf
24/02/10 (3)	1?	320	11	L	Quartz <2 organic cereal	32-51	17-54	19-24	~360	Light vit + curved - frags
	?(2)	1480	5	M-C	Quartz <4 up to 10	96-134	55-95	28-50	>400	Vit + curved – abraded frags
24/02/10 (4)	1?	230	1	F-L	Quartz ,1 organic cereal	84	68	39	380	Light vit + curved
	3?	415	1	M-C	Quartz <3mm	138	62	48 40t	?	Light vit – rim frag? – abraded
	?(2)	167	1	M	Quartz <3mm	85	?	?	?	Vit – v frag – no original ext surface – relined (11-16mm thick)
	?(3)	840	2	C	Quartz <4 up to 10	122 133	83 125	38 78	?	Heavy vit – no ext surf
25/02/10 (1)	2	1502	2	C	Quartz <4mm	169 99	188 70	46 51	?	Vit – lg frag curved – coils 33-50mm wide
	?	498	1	M-C?	Quartz	134	93	79	?	Fully vit – bowl curve on underside. Tuyere impression – metal prills
	3?	2390	5	L-M	Quartz <2mm	88-180	57-140	34-39	?	Straight – not vit but baked hard – rest abraded
	?(4)	68	1	F-L	Few Quartz <1 lot organic	88	41	14	300-350	Light vit – curved – int thin striations – abraded ext
	?(1)	330	1	C?	Quartz <3mm	119			?	Fully vit
25/02/10 (2)	?(3)	1840	2	C-VC	Quartz <5 up to 12	141 195	95 113	58 93	?	Heavy vit – abraded ext surf
25/02/10 (3)	?(2)	90	3	C	Quartz <4mm	<52			?	Abraded frag – 1 fully vit
25/02/10 (4)	1?	150	2	F-L	Quartz <1 organic cereal	57 74	38 50	38 28	360	Light vit + curved frags
	?(3)	706	3	C –VC	Quartz <5 up to 8	55-109	52-94	27-41	?	Heavy vit – no ext surf – 1 with rock surrounded by clay
25/02/10 (5)	?(1)	70	1	?	Quartz <3mm	64			?	Fully vit
25/02/10 (7)	?(1)	94	1	M-C?	Quartz	<60	?	?	?	V frag – fully vit – slag? Magnetic
25/02/10 (8)	1	760	5	F-L	Quartz <1 organic cereal	53-122	50-71	21-30	400	Light vit + curved – ext vertical linear imp
	?(3)	100	1	C	Quartz <5 up to 10	61	39	28	?	Heavy vit – no ext surf
26/02/10 (1)	1?	390	2	F-L	Quartz <1 organic cereal	84 152	63 93	28 31	360-380	Light vit + curved
	?(3)	480	3	C	Quartz <4 up to 7	51-113	43-93	30-45	?	Vit – no ext surf
	?(1)	180	1	?	Quartz <3mm	89			?	Fully vit
	?(2)	130	1	M-C	Quartz <3 up to 6	99			?	Heavy vit – no ext surf

Location	Type (FW)	Weight	No	Fabric	Inclusions	Length	Height	Width	Est. dia-meter	Notes
26/02/10 (3)	1?	1300	16	M	Quartz <3 up to 15	35-88	83	39	?	Vit + curved – few original surfaces – 1 maybe base
	?(2)	70	1	L-M	Quartz <1 up to 10	164	179	90	?	Heavy vit
	?(1)	1580	2	C?	Quartz <3 up to 8	<86			?	Fully vit
	?(2)	180	1	L-F	Quartz <1 organic cereal	62			?	Fully abraded
26/02/10 (4)	?(2)	80	3	M	Quartz <2mm	<58			?	No original surf. - abraded
	?(2)	340	1	M-C	Quartz <2 up to 7	111	89	42	?	Heavy vit – no ext surf
26/02/10 (5)	?(2)	150	1	M	Quartz <2mm	76	54	35	?	Light vit – abraded frag
26/02/10 (5/6)	1?	1750	8	M	Quartz <2 up to 5	50-120	120	63-55	Ext 400?	Vit + curved – 1 base no flare frag – 1 tuyere adhering
	?(2)	370	1	M	Quartz <2 up to 5	91		48	?	Heavy vit – vit around tuyere imp
26/02/10 (7)	1	650	4	F-L	Quartz <1 organic cereal	74-97	53-75	25-54b 48t	380-400	Light vit + curved – 1 base frag – ext ver linear striations
	?(2)	340	3	M	Quartz <3mm	57-68	58	53	?	Heavy vit – no ext surf
	?(3)	120	1	C	Quartz <4 up to 12	74			?	Heavy vit – no ext surf
26/02/10 (8)	1?	388	1	M	Quartz <3 up to 8	105	95	42	?	Vit – slight curve
	?(2)	338	2	M	Quartz <2	63-76	?	?	?	1 vit – v frag – other maybe daub
	?(2)		1	F-L	Quartz <2 organic cereal	48	34	28	?	Light vit – v frag
	?(2)	200	2	M-C	Quartz <3 up to 9	28-65	93	26	?	Vit – slightly curved – no ext surf
27/02/10 (2)	1	350	1	F-L	Quartz <1 organic cereal	94	60	63b 29t	?	Light vit + curved – abraded base frag
	?(2)	2920	1	L-M	Quartz <2 upto 15 – organic	249	163	155	?	Not vit – a collapsed furnace wall??
	?(3)	260	2	C-VC	Quartz <4 up to 10	63 88	37 79	35 41	?	Heavy vit – no ext surf
27/02/10 (3)	1?	190	1	F-L	Quartz <2 up to 6 organic cereal	68	93	29	Ext 380-400	Light vit + curved
	?(2)	881	7	L-M	Quartz <2mm	50-118	86	54	?	v frag – no original surfaces
27/02/10 (4)	1	2110	1	M	Quartz <3 up to 6	167	206	19b 48t	300-350	Heavy vit – curved base – melted at base – tuyere embedded
	1	946	1	M	Quartz <3 up to 6	150	100	48b 33t	350	Heavy vit – curved base – magnetic patch on vit
	3?	1220	5	M	Quartz <2 up to 6	43-156	134	50	none	Straight – no int surf – 1 reduced side
27/02/10 (5)	?(1)	50	1	C?	Quartz <5 up to 8	58		15	?	Fully vit frag
27/02/10 (6)	1?	1022	2	M	Quartz <5mm	144 140	63 95	28-21 48-40	300-350 200	Wall frags – light vit + curved
	1?	40	1	F-L	Quartz <1 organic cereal	44	33	22	?	Light vit + curved – abraded frag

Location	Type (FW)	Weight	No	Fabric	Inclusions	Length	Height	Width	Est. dia-meter	Notes
	?(2)	510	6	M	Quartz <2 up to 8	54-76	42-62	19-33	?	1 vit – others no int surf – abraded frags
	?(1)	800	1	C?	Quartz <3 up to 7	153			?	Fully vit
27/02/10 (7)	1	2340	1	M	Quartz <2 up to 5	176	143	44b 25t	300-350	Heavy vit – curved base – molten int – tuyere embedded
	?(2)	140	1	M	Quartz <2 up to 4	77	52	29	none	Flay surf – no vit – brick?
20/09/09 (3)	?(2)	440	2	M	Quartz <2mm	90 103	84 62	43 42	?	Vit – no ext surf.

Key:
F – fine **L** – low coarse **M** – medium coarse **C** – coarse **VC** – very coarse
? – data not relevant or too fragmentary to provide data
1b – base width **2t** – width at furthest surviving top part of base fragment
Vit – vitrified
V – very
Frag – fragmentary
Surf – surface(s)
Prob – probable
Int – internal
Ext – external
Type ?(1) – non –diagnostic (category)

Appendix C.4.1 – FS 1

Characteristic features	Flat vitrified base; light inner surface vitrification; thin walls; thicker walls at base which taper further up the furnace
Fabric	Most medium coarse fabric dominated by small quartz inclusions mostly <3mm but up to 16mm. A few fragments have low to medium coarse fabrics and the fragment from 12/02/10 (1) has a fine to low coarse fabric. The finer examples have a large quantity of organic inclusions
Size range	Up to 265mm in length, 326mm in height, 19-80mm in base thickness, 16-48mm thick at the furthest surviving height and estimated inner diameters between 240-400mm (most 300-350mm)
Locations in which found	Flaring base: 03/02/10 (11) (13) (14) (15), 05/02/10 (1) (7), 08/02/10 (4), 12/02/10 (1), 13/02/10 (1), 16/02/10 (1), 19/02/10 (3) (4) (5) (6), 23/02/10 (4), 26/02/10 (7), 27/02/10 (2) Thick base: 28/01/10 (5), 03/02/10 (6) (11) (13) (14) (15), 05/02/10 (7), 08/02/10 (3) (8) (9), 11/02/10 (6), 18/02/10 (3) (4) (6), 27/02/10 (4) (7) Rims: 08/02/10 (1), 12/02/10 (8), 18/02/10 (3) (6) Body frags (probable): 29/01/10 (2), 01/02/10 (8), 02/02/10 (8), 03/02/10 (6) (9) (10) (14) (15), 05/02/10 (1) (3) (4) (7), 08/02/10 (1) (2) (3) (8) (9), 09/02/10 (2) (6), 11/02/10 (1) (5) (6), 12/02/10 (1) (2) (7) (8), 13/02/10 (1) (3) (12) (13) (15), 15/02/10 (2) 16/02/10 (1) (2) (5) (6), 18/02/10 (2) (3) (4) (5) (6), 19/02/10 (3) (4) (5) (6), 21/02/10 (9), 23/02/10 (3) (8) (9) (10), 24/02/10 (1) (3) (4), 25/02/10 (4) (8), 26/02/10 (1) (3) (5/6) (7) (8), 27/02/10 (3) (6)

This furnace wall type is the most common in the assemblage. No furnace wall remains intact with the majority of the wall fragments being non-diagnostic. However in some instances there are better preserved base fragments which enable identification. These vary slightly in fabric, size and wall thickness but the general morphological characteristics which define this type are their flat, lightly vitrified bases, light inner surface vitrification, reasonably thin walls and their larger wall thickness at the base which tapers further up the walls. There are two major groups: those where the base flares out on the exterior (like an elephant foot) present at locations 03/02/10 (11) (13) (14) (15), 05/02/10 (1) (7), 08/02/10 (4), 12/02/10 (1), 13/02/10 (1), 16/02/10 (1), 19/02/10 (3) (4) (5) (6), 23/02/10 (4), 26/02/10 (7), 27/02/10 (2) and those where the base is thicker but does not flare (or less obviously) present at 28/01/10 (5), 03/02/10 (14), 05/02/10 (7), 08/02/10 (3) (8) (9), 11/02/10 (6), 18/02/10 (3) (4) (6), 27/02/10 (4) (7). In addition there are many furnace wall body fragments which lack the diagnostic bases but their sizes and curvatures or their association with better preserved bases point to a similar furnace type. These are present in locations 29/01/10 (2), 01/02/10 (8), 02/02/10 (8), 03/02/10 (6) (9) (10) (14) (15), 05/02/10 (1) (3) (4) (7), 08/02/10 (1) (2) (3) (8) (9), 09/02/10 (2) (6), 11/02/10 (1) (5) (6), 12/02/10 (1) (2) (7) (8), 13/02/10 (1) (3) (12) (13) (15), 15/02/10 (2) 16/02/10 (1) (2) (5) (6), 18/02/10 (2) (3) (4) (5) (6), 19/02/10 (3) (4) (5) (6), 21/02/10 (9), 23/02/10 (3) (8) (9) (10), 24/02/10 (1) (3) (4), 25/02/10 (4) (8), 26/02/10 (1) (3) (5/6) (7) (8) and 27/02/10 (3) (6).

05/02/10 (1)

19/02/10 (5)

08/02/10 (3)

08/02/10 (9)

The base fragments are up to 265mm in length, 326mm in height, 19-80mm in base thickness and 16-50mm thick at their utmost surviving height. However, the majority are between 40-60mm thick at the base tapering to 16-30mm further up the fragment. It is worth mentioning that not all fragments had their original width remaining with some showing significant melting of the interior walls while others had heavily abraded or broken exterior surfaces. A good example is a fragment from 27/02/10 (4) where the base thickness has been reduced to 19mm but the upper part of the wall indicates that its original thickness would have been in excess of 50mm. Many fragments were also quite short meaning that the thickness of the furnace walls further up from the base cannot be determined. Of special interest is that all of these base fragments are curved which enabled their inner diameters to be estimated between 240-400mm (most 300-350mm). The fragments from 03/02/10 (13) (15) have slightly thicker bases than the average at around 70-80mm while the fragments from 05/02/10 (7), 16/02/10/ (1), 18/02/10 (2), 19/02/10 (4) (6), 26/02/10 (7) have larger inner diameters than the average at around 350-400mm. Most furnace wall fragments are of a medium coarse fabric dominated by small quartz inclusions mostly <3mm but up to 16mm. A few fragments have low to medium coarse fabrics and the fragment from 12/02/10 (1) has a fine to low coarse fabric. The fragments from 03/02/10 (11), 05/02/10 (7), 08/02/10 (3) (4) (8) (9), 12/02/10 (1), 16/02/10 (1), 18/02/10 (3), 26/02/10 (7) and 27/02/10 (2) also have some organic component. These organic components are not easily identifiable by macro-analysis but there appears to be some charcoal and fibrous impressions in the fragments from 03/02/10 (11) while the others are dominated by seed or husk like impressions (sometimes inclusions <7mm in length). These may be from rice or millet or some sort of cereal. They are especially noticeable where the clay fabric has been abraded by post-depositional processes. The fragment from 12/02/10 (1) also seems to have some crushed slag or crucible fragments (<4mm) in the clay matrix.

All the furnace wall fragment bases are flat and baked hard or lightly vitrified, in some cases perhaps even with a thin layer of porous slag. This suggests that the furnace walls were built on a hard, flat surface and it is even possible that these furnaces had a stone base or plinth on which the clay walls were built. Some stone fragments were recovered with adhering vitrification adding credence to this hypothesis. These are discussed further in the geological section. All the base fragments have vitrification on their interior (concave) surfaces while the exterior (convex) surfaces are of an orangey or reddish oxidised colour. For the most part the vitrification is dull dark grey to black in colour and very thin (<5mm). It is generally of a solid medium sandpaper rough texture with few or no major projections of material. The fragments from 19/02/10 (4) (5) (6) have slightly rougher vitrification with many tiny sharp protrusions on the bottom parts of their interior surfaces forming a sort of crusty band which presumably went round the circumference of the furnace. This may have been where the furnace wall had been in contact with the molten slag which presumably accumulated at the bottom of the furnace. Fragments from 03/02/10 (13) (15), 13/02/10 (1), 19/02/10 (3) (4) (6) and 27/02/10 (4) (7) also have some rougher and sharper magnetic patches on the vitrified surfaces varying in colour from dark orange, purple to dark brownish-red. This is indicative of metallic iron content suggesting that these furnaces were more likely used for iron smelting or smithing than crucible steel production.

Some fragments from 28/01/10 (5), 05/02/10 (7), 11/02/10 (6), 19/02/10 (3) (6) and 27/02/10 (4) (7) have more vitrified inner surfaces. The vitrification is mainly dark grey to black in colour with rounded projections of molten furnace wall. This greater melting of the furnace walls is not surprising as the majority of these fragments have tuyeres embedded in them meaning that the walls surrounding the air supply would have been subject to higher temperatures. Indeed the vitrification appears more agitated beneath the tuyere nozzles. It is interesting that these tuyeres are all of type 2 but their morphological aspects as well as their positioning in the furnace walls has been discussed in the tuyere section. The vitrification is mainly low to medium rough in texture and reasonably solid, although, on some fragments there are a few spherical voids varying in size but usually <10mm. There are some charcoal impressions mainly <15mm but up to 30mm and these seem to have contributed to the undulated flowed appearance of the vitrified layer. Of special interest are the fragments from 19/02/10 (3) and 27/02/10 (4) (7) where their interior vitrification protrudes up to 50mm below the flat furnace base. This suggests that there must have been a depression in the ground (probably bowl shaped) at the base of the furnace or that the furnace itself was resting on something like a stone plinth allowing the slag to accumulate below the level of the furnace walls. This would explain the lack of adhering slag on most base fragments although there is some slag adhering to the fragment from 27/02/10 (7).

11/02/10 (6)

11/02/10 (6)

19/02/10 (3)

27/02/10 (4)

27/02/10 (7)

The furnace base fragments from 03/02/10 (13) (14) (15), 05/02/10 (1), 12/02/10 (1), 13/02/10 (1), 16/02/10 (1), 18/02/10 (3) and 19/02/10 (4) (5) (6) have identifiable parallel impressions or striations. These impressions may have been present on fragments from other locations but the abrasion or vitrification of their surfaces have covered up any traces. The internal linear impressions are primarily vertically aligned, going from the base of the fragments to their upmost surviving ends. These are between 5-15mm wide and no more than a few millimetres deep. They are slightly rounded in profile with the middle parts of the impressions being the deepest and the edges rising slightly. They appear to be parallel and most do not overlap. These are interesting as they suggest that the furnaces were built around bundles of branches or reeds which would have helped to support the weight of the wet clay, preventing the potential collapse of the furnace walls. Another possibility is that they are finger marks remaining from when the clay was smoothed to make the furnace walls more even and filling gaps between the different clay layers as the furnaces were built. In support of this is are a few fragments from 12/02/10 (1) and 19/02/10 (5) where their internal linear impressions are aligned on a horizontal axis or even sometimes at an angle. On many base fragments there are also similar linear impressions on the exterior surfaces (03/02/10 (13 (15), 12/02/10 (1), 13/02/10 (1), 16/02/10 (1), 18/02/10 (3) and 19/02/10 (4) (6)). In contrast to the internal impressions these are most often horizontally aligned or at an angle. They are not as linear and parallel (uniform) as the internal examples but have a greater tendency to overlap. These are most likely finger marks left in the clay when the exterior was smoothed.

03/02/10 (13)

03/02/10 (15)

05/02/10 (1)

12/02/10 (1)

13/02/10 (1)

16/02/10 (1)

18/02/10 (3)

Of special interest are other linear impressions present on most fragments from 19/02/10 (4) (6). These consist of many fine, tightly packed, sometimes overlapping striations (<2mm wide) all aligned in the same direction. These are mainly present on the bottom 60-90mm of the furnace bases where the fragments from these locations have lost their exterior surfaces. A very thin layer of clay (<2mm) appears to have chipped off in these areas revealing another surface underneath dominated by these striations. On the interior surface these are horizontal while on the exterior they are aligned vertically. It is uncertain how these were made and for what purpose but they may be evidence for the use of a brush to smooth the surfaces or even perhaps to roughen them, allowing the better adhesion of an exterior clay lining/coating. The base fragment from 26/02/10 (7) also has some fine linear striations on its exterior surface but they are fainter than the ones found on the fragments mentioned above. In addition, the base fragment from 19/02/10 (6) has striations on its flat base. These are fine (<2mm wide) and spaced approximately 5mm apart following the curvature of the fragment. No striations were found on any other bases. They may be impressions of the surface on which the furnace was built, or at least the surface on which the clay was shaped. The uniform parallel lines are similar to tree rings and it is a possibility that the clay was moulded or the base flattened on a tree trunk.

19/02/10 (4)

19/02/10 (4)

19/02/10 (6)

19/02/10 (6)

There are some potential type 1 base fragments in locations 29/01/10 (2), 11/02/10 (6), 12/02/10 (7) (8), 13/02/10 (15), 18/02/10 (6) and 23/02/10 (9) and 24/02/10 (1). All these fragments are poorly preserved with remains of flat, baked hard, or lightly vitrified bases but with heavily abraded surfaces making their identification difficult. However, the fragments from 12/02/10 (7) (8) and 13/02/10 (15) show the typical light, medium sandpaper rough vitrification characteristic of the type 1 furnace bases. The fragments from

29/01/10 (2), 11/02/10 (6), 18/02/10 (6) and 23/02/10 (9) have slightly heavier vitrification with rounded low to medium coarse flows which are also typical of some type 1 furnace bases. Their dimensions are consistent with the better preserved type 1 examples with a base thickness between 35-60mm (although some fragments have heavily abraded exterior surfaces) which tapers further up the fragments. They are all of a similar medium coarse fabric type dominated by small quartz inclusions <3mm although the fragments from 12/02/10 (6) (7) also have a significant proportion of organic inclusions. Three fragments from 29/01/10 (2), 18/02/10 (6) and 23/02/10 (9) have adhering tuyeres which are more than likely of the flaring type 2 kind.

11/02/10 (6)

12/02/10 (8)

13/02/10 (15)

18/02/10 (6)

23/02/10 (9)

In addition, five potential furnace rim fragments were found in locations 08/02/10 (1), 12/02/10 (8) and 18/02/10 (3) (6). These have one rounded edge, are consistent with type 1 furnace thickness being between 20-40mm and have the typical thin light vitrification. The fragments from 08/02/10 (1) and 18/02/10 (7) are better preserved and their curvatures indicate a similar inner diameter at 260-380mm. One of the examples from 08/02/10 (1) also has the typical linear, vertically aligned internal impressions up to 11mm wide. Their fabrics (except the one from 12/02/10 (8) which is medium coarse) are fine to low coarse with some quartz inclusions <4mm and a large quantity of organic material resembling some sort of cereal grain.

08/02/10 (1)


18/02/10 (3)


08/02/10 (1)

There are also many potential furnace lining type 1 body fragments. As these are missing the base and rim ends of the furnaces, they are difficult to identify, but all have certain morphological properties which suggest that they are associated with the type 1 furnace lining. They are all between 10-62mm in thickness with most between 16-30mm. Most are of the typical medium coarse fabric dominated by small quartz inclusions and in the case of the fragments from 02/02/10 (8), 03/02/10 (9) (10) and 13/02/10 (15) also with some organic fibrous material. The fragments from 02/02/10 (8) have a low coarse fabric with some thin, elongated organic material up to 12mm in length. Some fragments from 01/02/10 (8), 03/02/10 (6) (9), 05/02/10 (4), 08/02/10 (1) (2) (8) (9), 09/02/10 (6), 11/02/10 (5), 12/02/10 (1) (2), 13/02/10 (12), 15/02/10 (2), 16/02/10 (1) (6), 18/02/10 (4) (5) (6), 19/02/10 (3) (5) (6), 21/02/10 (9), 23/02/10 (3) (10), 24/02/10 (1) (3) (4), 25/02/10 (4) (8), 26/02/10 (1) (7) and 27/02/10 (3) (6) have finer fabrics (fine to low coarse) with some small quartz inclusions but dominated by the usual organic material resembling some sort of cereal grain. The examples from 03/02/10 (9), 15/02/10 (2) and 16/02/10 (1) have more low to medium coarse fabrics with a higher quantity of quartz than the others. The fragments from 12/02/10 may also have some small slag inclusions <3mm.

All fragments except those poorly preserved have oxidised orangey coloured exterior surfaces and vitrified interior surfaces. Most have the typical light and thin medium sandpaper rough vitrification. The only exceptions are some fragments from 05/02/10 (3) (7), 08/02/10 (3), 09/02/10 (6), 11/02/10 (6), 13/02/10 (3), 16/02/10 (2) (5), 18/02/10 (2) (3) (6), 19/02/10 (3), 23/02/10 (9) and 26/02/10 (8) which have a slightly heavier rounded flow vitrification up to 20mm thick. Many of the fragments are also curved indicating similar inner diameters (240-400mm) to the better preserved base fragments discussed above. However, some fragments from 05/02/10 (3) (4), 08/02/10 (3) (8), 09/02/10 (2) (6), 12/02/10 (2), 13/02/10 (1) (15), 16/02/10 (2) (5), 18/02/10 (3), 19/02/10 (3) (5) and 26/02/10 (3) are very small and fragmentary (<120mm). Due to their small size their internal diameters cannot be estimated but they have the correct fabric, wall thickness and vitrification to have been type 1 furnace lining. One fragment from 18/02/10 (6) shows evidence for having been re-lined with two layers of vitrification separated by a non-vitrified clay layer.

Of special interest are the fragments from 03/02/10 (9) (10) (13) (14) (15), 05/02/10 (1), 08/02/10 (1), 09/02/10 (6), 11/02/10 (1) (5), 13/02/10 (1), 16/02/10 (1) (6) 19/02/10 (4) (5) (6) and 24/02/10 (1) which have vertically aligned linear impressions on their interior (concave) surfaces. These are between 8-15mm wide and are similar to the ones found on the furnace bases. Some of these impressions overlap slightly. Once again these are either marks left by bundles of branches/reeds used to help build the furnaces or finger marks. The fragment from 16/02/10 (1) has impressions on both internal and external surfaces and some of these are at a slight angle suggesting that they were more likely finger marks left when the clay was smoothed than branch impressions. Some examples from 01/02/10 (8), 03/02/10 (15), 13/02/10 (3), 23/02/10 (8) and 25/02/10 (8) on the other hand have vertical and angled linear impressions only on their exterior convex sides. Some of the fragments from 03/02/10 (14) (15), 12/02/10 (1) (2), 18/02/10 (4), 19/02/10 (4) (6) and 26/02/10 (7) also have finer 'brush-like' linear striations comparable to some of the more complete furnace bases above. The ones from 12/02/10 (1) (2) have these on both sides while on the others they are only present on the exterior side. These are aligned horizontally on the interior surface and almost vertically or at a slight angle on the exterior surfaces.

It is worth mentioning that many of the larger base fragments discussed above have clean (almost flat) breaks on their upper parts meaning that uniform chunks of furnace wall must have detached. This is also seen on some body fragments (from 03/02/10 (14) (15), 08/02/10 (1), 09/02/10 (6) and 12/02/10 (1)) which have broken cleanly with almost perfectly flat fractures. These give a clue on how these furnaces may have been built. They are between 35-50mm in height with smooth inner and outer surfaces (but curved) suggesting that the furnaces may have been built by adding slabs of clay 35-50mm tall on top of each other. The clay may have been allowed to dry partially before a subsequent layer was added, or, perhaps the layers were not perfectly moulded together, resulting in weakness at the join which would have broken more easily after deposition. This is supported by the fact that one body fragment from 19/02/10 (4) with a clean fracture fits perfectly on top of the type 1 furnace base of the same location.

03/02/10 (9)

03/02/10 (9)

03/02/10 (14)

03/02/10 (15)


05/02/10 (1)

16/02/10 (1)


16/02/10 (1)


16/02/10 (6)


18/02/10 (4)


25/02/10 (8)

12/02/10 (1)

Appendix C.4.2 – FS2

Characteristic features	Coil built; thick walls
Fabric	Mostly coarse to very coarse dominated by quartz inclusions <10mm with perhaps some organic material like charcoal. A few being low to medium coarse with some quartz inclusions <2mm.
Size range	Up to 268mm in remaining length, up to 222mm in remaining height and between 45-90mm thick
Locations in which found	29/01/10 (1), 08/02/10 (8) (9), 23/02/10 (3) (7), 25/02/10 (1)

Several type 2 fragments were found in locations 29/01/10 (1), 08/02/10 (8) (9), 23/02/10 (3) (7) and 25/02/10 (1). Their major characteristic feature is that they are coil built with rounded coils stacked on top of each other. They also have reasonably thick walls. The fragments are very fragmentary with no intact edges remaining. They survive up to 268mm in length, 222mm in height and are between 45-90mm in wall thickness. All except the fragment from 23/02/10 (7) have curvature but the majority are too small for their inner diameters to be estimated. The largest fragment was recovered from location 08/02/10 (9) and its curvature indicates an inner diameter greater than 500mm. Most fragments have a coarse to very coarse fabric dominated by medium to large quartz inclusions (<10mm) in a friable clayey matrix. Some also show signs of an organic component which was most likely charcoal. The fragments from 23/02/10 (3) (7) have low to medium coarse fabrics containing smaller quartz inclusions (<2mm).

All fragments have one non-vitrified exterior (convex) surface and one vitrified interior (concave) surface. Some of the fragments have lost parts of their exterior surfaces to abrasion or chipping of the material. This is no doubt due to post depositional processes but many do seem to retain the majority of their original thickness. These exterior surfaces are for the most part dark grey reduced in colour. The exception is the fragment from 23/02/10 (3) which is of a dark reddish-orange colour. Of special interest are the way in which these walls were built. All fragments have very distinct horizontal join lines visible on their exterior surfaces. These appear to have been made by the joining of large coils of clay which were stacked on top of one another. On the better preserved examples these coils still retain a rounded shape with a thin smoothed surface. It is interesting that all these coils are of a similar width ranging from 33-50mm wide. Some fragments from 29/01/10 (1), 08/02/10 (8) and 08/02/10 (9) cannot positively be ascribed to this type as they are very fragmentary, often with no or few remaining original surfaces. However, their fabrics, colouration, vitrification and sizes are very similar to the larger fragments and their coils suggesting that they are likely to be of this type. One fragment from 29/01/10 (1) is unusual. It is a curved, very coarse fragment with one rounded edge indicating that it may have been part of a rim. It is slightly thicker than the other walls at 90mm and is orangey oxidised in colour with no signs of having been subject to high temperatures. This is puzzling but it could have been part of an unused coil. Unfortunately its fragmentary nature limits further interpretation.

Their interior surfaces are all heavily vitrified. The majority of fragments have low to medium rough dark grey to black vitrification consisting of small to medium rounded projections and undulations. These undulated surfaces appear to have partially formed around charcoal, as evidenced by the large quantity of impressions up to 30mm in length (particularly in the fragments from 08/02/10 (9), 23/02/10 (3) (7) and 25/02/10 (1)). On some there are slightly rougher parts where the vitrification has become more agitated or areas where small sharp protrusions dominate. Some fragments from 08/02/10 (8) have smoother vitrification with smaller rounded projections. Most of the vitrified surfaces are solid with only a few small spherical voids. There is increased porosity underneath the vitrification where greater concentrations of small spherical voids are present. This is noticeable on the fragments' broken edges and in parts where the vitrification has chipped. The exception is the largest fragment from 29/01/10 (1) which is semi porous with many globular and spherical voids (<10mm) present on the surface of the vitrification. Of special interest is the presence of small green glassy patches on the fragments from 23/02/10 (3) and 25/02/10 (1). These resemble the green glassy slaggy material found on crucible sites suggesting that these were furnace fragments used for crucible steel production. If this is the case it is uncertain whether this green glassy material derives from the increased vitrification of the furnace walls or from a potential flux added during the process which subsequently fused to the furnace walls.

Some fragments have dark reddish-orangey-brown and dark brownish-red patches on their vitrified internal surfaces but none are magnetic. This may support the idea that these furnace fragments were used in the crucible steel production process. It is also worth noting that although most fragments of this type are very similar in shape, size and fabric, the fragments from locations 23/02/10 (3) (7) have much finer fabrics and one has no curvature. These fragments may therefore represent a different technology. Many other coarse to very coarse ceramic fragments were recovered but these have abraded non-vitrified (external) surfaces meaning that it cannot be certified whether or not they were coil built. These examples have been classified in the non-diagnostic section as category 3.

29/01/10 (1)

29/01/10 (1)

08/02/10 (8)

08/02/10 (9)

08/02/10 (9)

23/02/10 (3)

23/02/10 (7)

25/02/10 (1)

25/02/10 (1)

Appendix C.4.3 – FS3

Characteristic features	Straight wall profile; vitrification on one side; reasonably thick walls
Fabric	Varies from low coarse with very few quartz to very coarse with a significant proportion of quartz inclusions. Many also have some organic component.
Size range	Vary from 58-267mm in length and 25-80mm in thickness.
Locations in which found	25/01/10 (6), 29/01/10 (1), 05/02/10 (2) (4) (7), 08/02/10 (1), 17/02/10 (1) (3) (4) (6), 18/02/10 (1) (4), 24/02/10 (1) (4), 25/02/10 (1), 27/02/10 (4)

Several unusual furnace lining fragments were identified in 25/01/10 (6), 29/01/10 (1), 05/02/10 (2) (4) (7), 08/02/10 (1), 17/02/10 (1) (3) (4) (6), 18/02/10 (1) (4), 24/02/10 (1) (4), 25/02/10 (1) and 27/02/10 (4). Their major characteristic feature is that they are not curved but straight walled refractory fragments. In addition, most seem to have one vitrified side suggesting that they were associated with the metal production or refining occurring at these locations. For the most part the wall thickness is greater than the average fragments of the other types even though many appear to have lost a significant proportion of their width with the non-vitrified side often being heavily abraded or broken. The size of the fragments varies from 58-267mm in length while their thickness varies from 23-80 with most between 30-60mm. Most of their edges are broken and their fabrics vary considerably. The fragments from (17/02/10 (1) (4) (6) have a low coarse fabric with a fine silty dark brownish-red clay matrix, a few quartz inclusions (<2mm) and evidence for some organic content in the form of fine elongated impressions up to 30mm in length and 2mm wide. This may have been straw or twigs and the impressions are especially visible on the non-vitrified surface perhaps indicating that the clay was coated with something; maybe dung like I observed with the Azurs. Of interest is the smallest fragment from 17/02/10 (6) which contains a considerable amount of very small white inclusions which may be crushed rice husks or bone. The other fragments vary from medium coarse fabrics to very coarse fabrics dominated by quartz inclusions mostly <3mm but up to 10mm in the fragment from 29/01/10 (1). The fragments from 05/02/10 (4) (7) may also have had some sort of fibrous organic material as small elongated impressions are visible on the surfaces. There may have been some charcoal in the fragment from 18/02/10 (1).

All fragments have one non-vitrified side usually of an orangey oxidised colour or dark brownish-red for those in 17/02/10 (1) (4) (6) and 18/02/10 (1). The fragment from 29/01/10 (1) is missing most of its non-vitrified side meaning that it is mostly dark grey reduced in colour. All type 3 furnace wall fragments have one vitrified side. The exceptions are those found in locations 05/02/10 (2), 08/02/10 (1), 25/02/10 (1) and 27/02/10 (4). These are missing the majority of their vitrified sides leaving abraded dark grey reduced surfaces. The largest fragment from 25/02/10 (1) also does not appear to be vitrified but has a hard baked surface. The vitrification on the other examples varies. The fragments from 29/01/10 (1), 05/02/10 (4), 17/02/10 (1) (3) (4) (6), 18/02/10 (4) and 24/02/10 (4) have thin (mostly <10mm) and reasonably flat dark grey to black vitrification. They have no major protrusions of material and most are medium sandpaper rough in texture. The fragment from 18/02/10 (4) has a slightly rougher, thin vitrified crust with many tiny sharp protrusions of material. Most of these vitrified sides are solid on the surface but the fragment from 29/01/10 (1) is of low to medium porosity with many small spherical voids. Some of its vitrification is also glassy in nature. There does appear to be increased spherical porosity underneath some of the vitrification but on the whole most are reasonably solid. The largest fragment from 17/02/10 (1) has some shallow charcoal impressions up to 50mm in length. The ones from 05/02/10 (7) and 18/02/10 (1) have thicker (up to 20mm) vitrification with rounded molten clay flows and undulations. They are dark grey to black and mainly of low to medium coarseness with small protrusions of material. In some areas there are larger protrusions or ridges where the vitrification appears to have partially folded on itself. They also have some very small greyish-white specks on their surfaces which must be partially melted quartz inclusions. In addition, there are very small spherical voids (<4mm) present on the parts where the vitrification has chipped off. Some of the vitrified surfaces (05/02/10 (7), 18/02/10 (4) and 24/02/10 (1)) have orangey-brown or dark brownish-red patches which are magnetic suggesting high metallic iron content. It is therefore likely that these fragments were part of a metallurgical process.

29/01/10 (1)

05/02/10 (4)

05/02/10 (7)

17/02/10 (3)

17/02/10 (6)

Of special interest are some of the fragments from 25/01/10 (6), 05/02/10 (2) (7), 18/02/10 (4) and 24/02/10 (1) (4) which have one unbroken rounded edge suggesting that they are rim fragments. This is supported by the fact that their thickness tapers from their body to the rounded rim edge and that there is less vitrification close to these edges. The rounded rim edges on the fragments from 18/02/10 (4) and 24/02/10 (4) are not flat but start to curve downwards towards one of the broken edges suggesting that they came from straight walls with rounded ends. The largest fragment from 05/02/10 (7), the medium one from 17/02/10 (1) and the smallest from 17/02/10 (6) have one unbroken flat edge. These are baked hard and suggests that they are base fragments. Their relatively poor preservation limits further interpretation but it seems likely that these type 3 straight wall fragments came from smithing hearths. The straight walls would have been used to retain the charcoal heaped allowing an air supply to be directed within so that the required temperature could be reached. Ethnographic surveys on modern rural smithies conducted during the Pioneering Metallurgy Project have shown that this smithing method with a straight ceramic clay wall appears to be the norm in Telangana.


05/02/10 (2)


05/02/10 (7)

18/02/10 (4)

24/02/10 (1)

24/02/10 (4)

17/02/10 (1)

17/02/10 (6)

As a further note there are finger or thumb marks on the non-vitrified surface of the fragment from 05/02/10 (4) and fine linear horizontal 'brush-like' striations on the non-vitrified side of the fragment from 18/02/10 (4). These striations are very similar to those found on some of the type 1 base fragments.

Appendix C.4.4 – FS4

Characteristic features	Almost complete; very thick wall with flat base; many tuyere fragments used in wall construction
Fabric	Coarse fabric dominated by small quartz inclusions <5mm but up to 12mm
Size range	One fragment 260mm long, 156mm in height, 112mm wide at the base tapering to 73mm at the top of the surviving wall
Locations in which found	23/02/10 (9)

There is one almost complete base fragment from location 23/02/10 (9). It is 260mm long, 156mm in height and 112mm in width at the base tapering to 73mm at the top of the surviving wall. However, the exterior surface of the wall is broken so it would originally have been wider. It appears to be reasonably straight but may have a slight curvature with the vitrified side on the interior surface. The base is flat and baked hard meaning that it must have been resting on a flat surface – either the ground or a stone base. Of special interest is the composition of the ceramic wall. Since the original outer surface is broken it reveals many curved tuyere fragments. These appear to have been used with dark grey reduced areas and perhaps even vitrification on their surfaces. Most fragments are approximately ⅓ of the original tuyeres' circumference. They have been stacked with the convex side facing up but there is one fragment which is convex side down. By majority these tuyeres are of the flaring type 2 (see chapter 5.3) but there does seem to be another type with slightly thicker walls and no major flare (perhaps the thicker walled type 2). It is possible that these were tuyeres that broke during firing and subsequently replaced but the large quantity of them (at least 7 fragments) would suggest that used tuyeres were purposely placed in the wall. These fragments are held together with a coarse clay dominated by medium to large quartz crystals up to 12mm but mainly <5mm. The clay is fully reduced medium to dark grey in colour and appears to have been heavy abraded, probably after deposition.

In the middle of the fragment sitting on the base is a thin walled tuyere with complete circumference. There is no clay between the tuyere and the flat base suggesting that it must have been placed on the ground and the wall built around it. It is about 115mm in length but the rim end is missing meaning that it would have been longer. Since the rim is missing it cannot be attributed to a particular type but the inner diameter is pretty consistent at

37mm at the closest end to the rim to 36mm at the nozzle. This means it is unlikely to have been of the flaring type 2 but more of a small to medium sized tubular non-diagnostic type. The nozzle of the tuyere protrudes about 50mm from the vitrified furnace wall and the tuyere was placed pretty much flat with no major angle. The wall thickness varies from about 12-15mm and it is made of a medium coarse fabric.

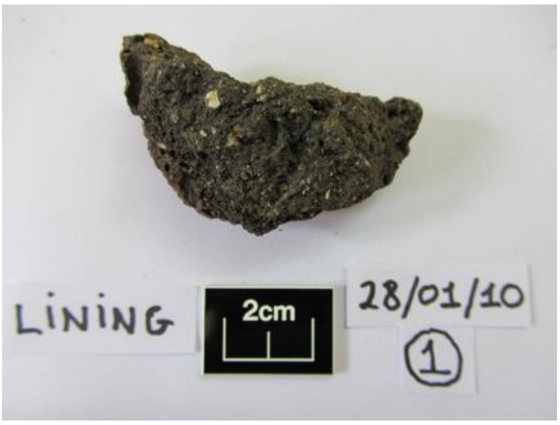
The wall vitrification is quite flat with no protrusions but it is uneven with smooth to low rough undulations. It is mainly dark grey to black but does have some brown patches especially around the main tuyere. Where the vitrification has been abraded there are many tiny spherical voids apparent (mostly <3mm). Of interest is that the fragment is quite symmetrical with the main tuyere placed directly in the centre. Both ends of the ceramic wall are baked hard suggesting that these were original surfaces. However, the vitrified interior surface seems to protrude slightly at either ends where the clay is baked indicating that it may have been larger. Even so, its small size would mean that it could be transportable if required but there are no signs of re-use as the vitrified side does not show layering. Another interesting feature is that the vitrification also protrudes below the flat furnace base by a couple of centimetres suggesting that there was a depression in the ground in front of it where the charcoal may have been heaped. This wall fragment is likely to have been a smithing hearth wall, perhaps of reasonably recent date but could have been contemporary with the smelting activity.

23/02/10 (9)

Appendix C.4.5 – FWND1, 2, 3, 4

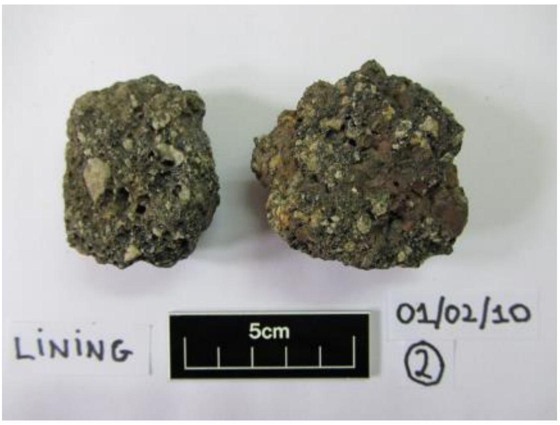
Many furnace lining fragments were recovered which do not display any of the major characteristic features which have enabled the fragments above to be grouped by type. The majority display similar fabrics and vitrification as the ones already discussed but for the most part they are either too fragmentary or vitrified to enable identification. The fragments fall into four main non-diagnostic categories. **Category 1:** those that are amorphous and fully vitrified present in locations 28/01/10 (1), 30/01/10 (1) (2), 01/02/10 (2) (5), 02/02/10 (4), 03/02/10 (6), 06/02/10 (2), 08/02/10 (1) (4) (5), 09/02/10 (6), 10/02/10 (1), 16/02/10 (2), 17/02/10 (1) (2), 18/02/10 (1), 19/02/10 (1) (3) (4) (5), 21/02/10 (1) (3) (4) (9), 22/02/10 (1), 23/02/10 (1), 24/02/10 (2), 25/02/10 (1) (5) (7), 26/02/10 (1) (3) and 27/02/10 (5) (6). **Category 2:** those that have lost the majority of their original surfaces and are either not vitrified (or the vitrification as chipped off) present in locations 25/01/10 (3) (6), 03/02/10 (6) (12), 05/02/10 (6), 08/02/10 (4), 11/02/10 (2), 12/02/10 (1) (3) (5) (6), 15/02/10 (1), 17/02/10 (3), 18/02/10 (1), 19/02/10 (3) (5), 22/02/10 (3), 23/02/10 (1) (7) (11), 25/02/10 (3), 26/02/10 (3) (4) (5) (8) and 27/02/10 (3) (6) (7) or those that have one vitrified side but missing the exterior surface present in locations 25/01/10 (6), 26/01/10 (8), 28/01/10 (5), 01/02/10 (6), 02/02/10 (1) (6), 03/02/10 (1) (3) (4) (7) (11), 05/02/10 (2), 08/02/10 (3) (4) (9) (10), 09/02/10 (6), 10/02/10 (1) (2), 12/02/10 (1) (4) (6), 13/02/10 (2), 15/02/10 (3) (4), 16/02/10 (6), 17/02/10 (2) (6), 18/02/10 (2) (3) (5), 19/02/10 (5) (6), 23/02/10 (1) (2) (3) (4) (6) (12), 24/02/10 (2) (3) (4), 26/02/10 (1) (3) (4) (5/6) (7) (8) and 20/09/09 (3). **Category 3:** coarse to very coarse friable clay lumps with heavy rounded vitrification on the interior side and an abraded/broken exterior side present in locations 28/01/10 (5), 29/01/10 (1) (3), 01/02/10 (1) (2) (3) (4) (5), 02/02/10 (5) (7), 03/02/10 (9) (13) (14) (15), 05/02/10 (1), 06/02/10 (2), 08/02/10 (1) (2) (4) (10), 09/02/10 (1) (5), 10/02/10 (1), 11/02/10 (2) (5), 13/02/10 (1) (2) (11), 15/02/10 (2), 16/02/10 (1) (5), 17/02/10 (2) (3), 18/02/10 (7), 19/02/10 (3) (4) (5) (6), 21/02/10 (3) (7), 22/02/10 (1), 23/02/10 (6) (8) (10) (12), 24/02/10 (1) (4), 25/02/10 (2) (4) (8), 26/02/10 (1) (7) and 27/02/10 (2). **Category 4:** thin curved fragments without any significant vitrification which may be pottery present in locations 29/01/10 (4) (5), 01/02/10 (6), 02/02/10 (7), 05/02/10 (3), 12/02/10 (2) (6), 17/02/10 (1) and 25/02/10 (1).

Category 1: These fragments are fully vitrified, amorphous in shape and small in size (<131mm). Their fabrics range from medium to very coarse dominated by quartz inclusions mostly <3mm in size but it is often hard to tell due to the heavy vitrification. The vitrification is most often dark grey to black in colour with some dotted whitish-grey partially melted quartz crystals. It varies in texture but most show well molten rounded projections of medium roughness. Many also have charcoal impressions adding to the agitated look of the surfaces. A few fragments have some small dark purplish-red or brownish-red patches which are magnetic.



28/01/10 (1)

30/01/10 (2)



01/02/10 (2)

25/02/10 (1)

Category 2: The non-vitrified fragments usually vary from an orangey oxidised colour to a dark grey reduced colour. Most have lost all their original edges and cannot be identified. They range in size from 66-115mm but there is one large fragment from 12/02/10 (1) which is up to 211mm. Most of their fabrics are medium to coarse once again dominated by quartz inclusions mainly <5mm. The larger fragment has a finer fabric (low coarse) with some quartz inclusions but a high proportion of organic fibrous material (impressions up to 50mm in length and 5mm wide) as well as some charcoal and maybe one small slag inclusion. Some of the fragments from 05/02/10 (6), 22/02/10 (3) and 26/02/10 (3) (8) have fine fabrics dominated by organic cereal looking inclusions (similar to some of the type 1 fragments). Of special interest is the amorphous fragment from 25/01/10 (3) which has two pottery sherd inclusions 10-20mm in size. None of these fragments have any diagnostic traits and their lack of vitrification also means that they may not have been part of a metallurgical process. One fragment from 17/02/10 (3) however, may have been a furnace base. It is slightly curved with medium to dark grey reduction on the concave side and seems to have a flat underside. It is 115mm in length, 60mm in height and up to 64mm at the base. Its curvature points to an inner diameter in excess of 500mm. Unfortunately it is poorly preserved with all surfaces heavily abraded and the external surface missing. Once again its lack of vitrification means that it cannot be proved to have been part of a furnace.

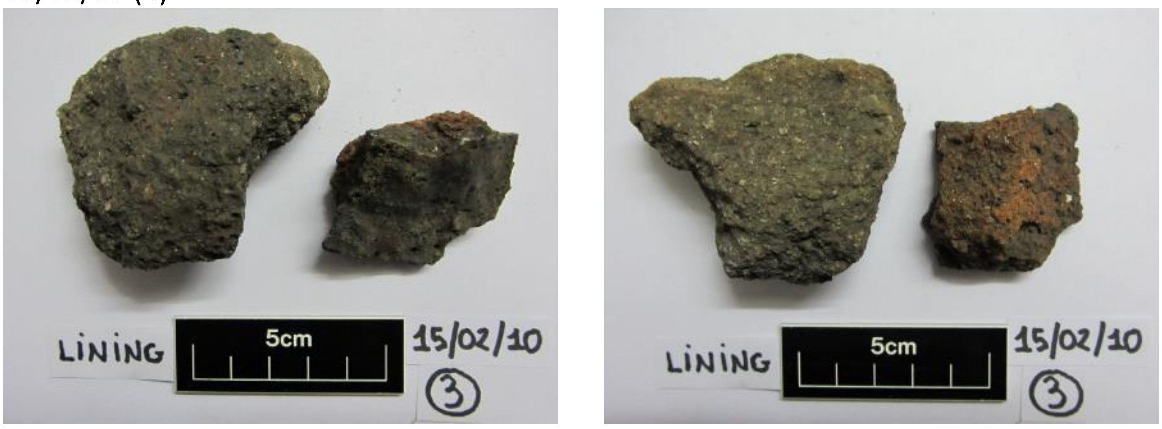
25/01/10 (3)

05/02/10 (6)

17/02/10 (3)

The other fragments in this category are missing their external (or non-vitrified) surfaces with the majority either broken off or heavily abraded. They are also all missing their original edges with no apparent base or rim ends. Their vitrification is similar to those of the larger diagnostic fragments discussed above, ranging from relatively smooth or low rough with well-rounded small projections to more agitated, rougher and shaper protrusions often accentuated by charcoal impressions. These vitrified surfaces also vary in porosity with most having at least some spherical or globular voids mainly <10mm in size. Some fragments have different coloured patches on their vitrification usually of a dark brownish-red colour. These are magnetic suggesting some metallic iron content. Their fabrics range quite considerably from fine and silty to coarse dominated by quartz inclusions. Some also have a fibrous organic content. They are usually small <150mm but there are a few larger fragments up to 215mm in size. Due to their small and fragmentary nature many do not show signs of curvature but some of the larger fragments do. Since these all have some form of vitrification they were likely associated with the metallurgical activities recorded at these locations. The fragment from 24/02/10 (4) shows evidence for having been re-lined as it has two layers of vitrification with non-vitrified clay in between. The fragment from 03/02/10 (3) has the remains of a tuyere on one side. It cannot be positively identified due to poor preservation but may be a type 2 tuyere.

03/02/10 (4)



15/02/10 (3)

03/02/10 (7)

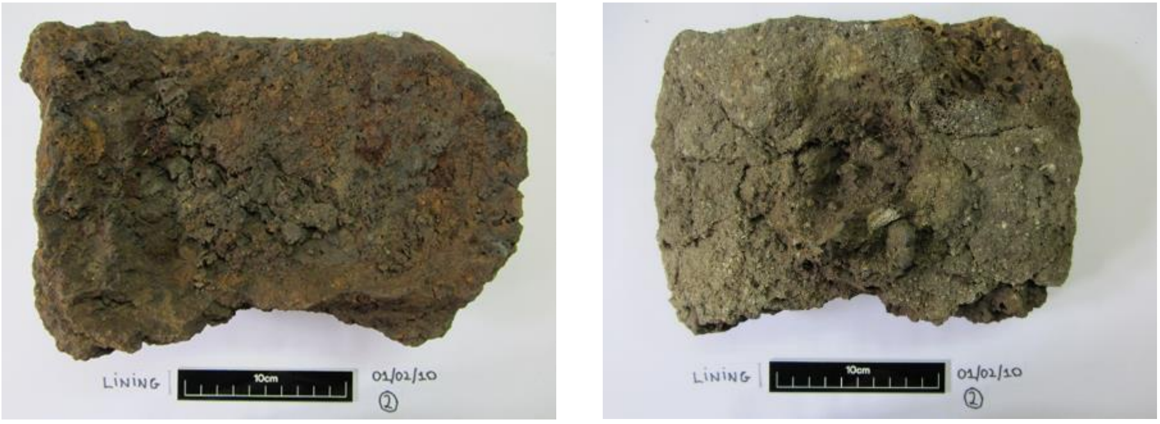
24/02/10 (4)

Category 3: The furnace lining fragments in this category deserve special mention as they differ from any other type discussed above. All examples are broken on all sides and none have surviving original non-vitrified sides. Their main characteristic is that they have coarse to very coarse fabrics dominated by quartz inclusions mainly <5mm in size but up to 17mm. The fragment from 08/02/10 (1) also appears to have a chalk or limestone inclusion (17mm). All examples have heavy vitrification on one side and are mostly dark grey reduced on the opposite side. In some cases these non-vitrified sides are more of a dark reddish or orangey colour with clear graduation of colour from these oxidised reddish parts to the more dark grey reduced areas. Many appear to come from locations with type 1 furnace wall technology (could have been a coarser clay lining on the interior of the furnaces) but some may be associated with the type 2 furnace coil technologies. Unfortunately, due to their poor preservation (abraded non-vitrified sides) they cannot be attributed to one of the more defined types described above. The vitrification on most is heavy with dull black melted and rounded projections medium to rough in texture. This vitrification often has charcoal impressions up to 55mm in size making the appearance look more agitated. In some examples there are also very small sharper protrusions giving certain areas a coarse sandpaper texture. Some small spherical voids are apparent on the surfaces especially in areas where the projections have broken or chipped. It is important to mention that many of these coarse fragments have magnetic patches on their vitrified sides. These are usually small areas that are of dark brownish-orangey-red colouration.

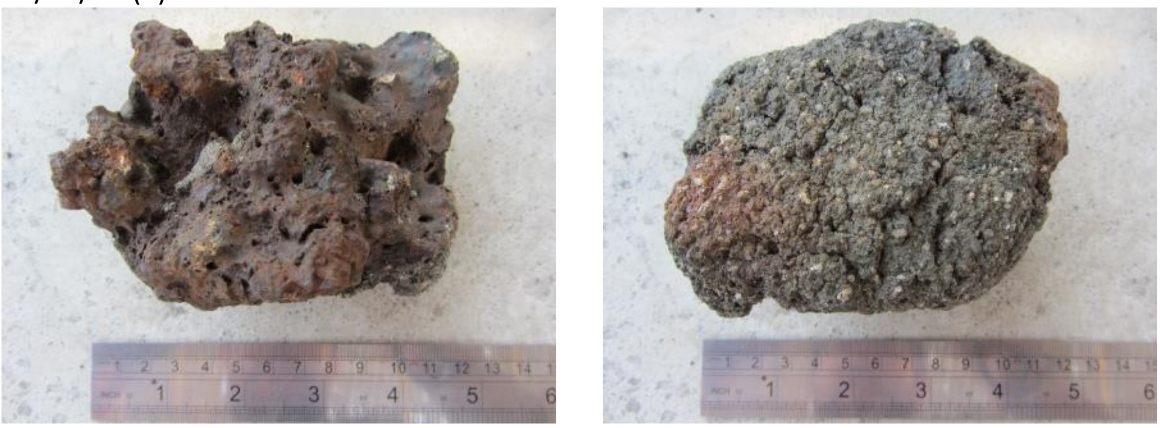
The examples from 06/02/10 (2), 08/02/10 (1), 09/02/10 (1), 10/02/10 (1), 17/02/10 (2) (3), 21/02/10 (1) and 22/02/10 (1) appear slightly different with vitrification that is very reminiscent to those found on crucibles and the type 2 furnace walls. It tends to be of a dark grey to black colour with a significant proportion of greyish-white partially melted quartz crystals either dotted or forming larger patches. The vitrification usually has well-rounded molten projection varying from medium to rough in texture. It is also interesting that some have small areas with pale to dark green vitrification. This vitrification is sometimes quite dull but on others it is almost glassy translucent. The fragment from 06/02/10 (2) has some very small magnetic metallic prills adhering to the vitrification suggesting that it was part of a furnace for crucible steel production. In addition it has two elongated rounded impressions which closely resemble the tong-marks left on some of the crucible lids. In the case of these fragments it is possible that they are abraded type 2 fragments.

A few fragments have special features which deserve mention. The largest example from 16/02/10 (1) has many dark orangey patches on its vitrified side which are heavily magnetic. The largest fragments from 03/02/10 (14) and 11/02/10 (5) are interesting because they are the only very coarse fabric furnace walls with surviving external (non-vitrified) surface. This surface is orangey oxidised while the internal surface is heavily vitrified with bulbous well molten projections. The fragment from 13/02/10 (1) also has a very small tuyere fragment (nozzle end) adhering on one edge but due to its fragmentary nature it cannot be attributed to any of the tuyere types. One of the fragments from 25/02/10 (4) has a large quartzite stone 55x48x42mm in size with vitrified clay (15mm thick) on one side suggesting that larger stones/rocks may have been used in furnace construction. The two examples from 01/02/10 (2) are large (up to 222mm in length) and are curved. Due to the heavy melting of the walls it is not possible to estimate the inner diameter. Their exterior (concave) surfaces are heavily abraded and dark grey reduced in colour. It is also possible that the vitrified sides contain slag as well.

01/02/10 (1)



01/02/10 (2)



03/02/10 (13)


03/02/10 (14)

06/02/10 (2)

08/02/10 (1)

09/02/10 (1)


11/02/10 (5)


13/02/10 (1)

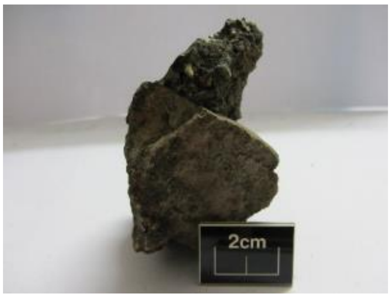

16/02/10 (1)


17/02/10 (2)


23/02/10 (12)


24/02/10 (1)


25/02/10 (4)

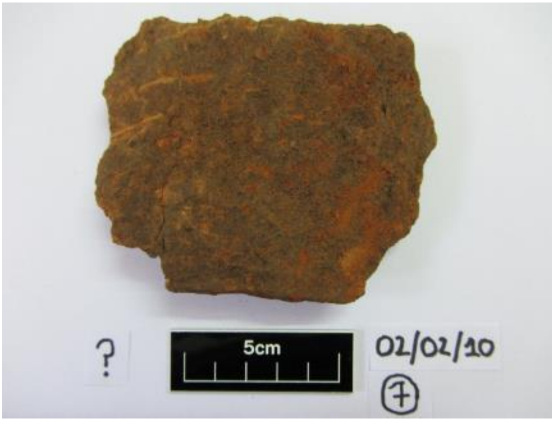


25/02/10 (4)

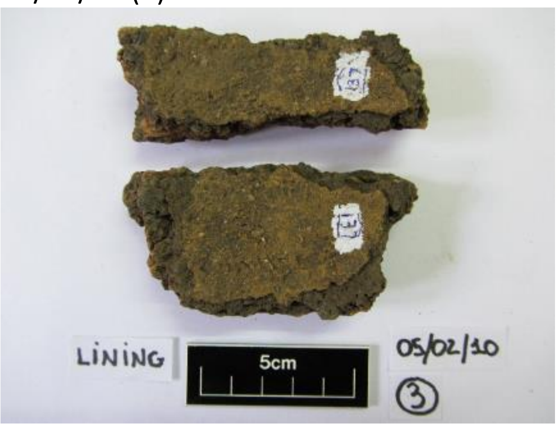
Category 4: These fragments are different to any of the other non-diagnostic fragments. The majority are small <111mm and thin between 9-20mm with most having a slight curvature. They are all made of a fine to low coarse fabric containing very few small quartz inclusions <1mm and dominated by a cereal grain organic component. The only exceptions are the fragments from 29/01/10 (4) (5) and 17/02/10 (1) which are up to 24mm thick. They also have fabrics dominated by very small white organic inclusions similar to those identified in the unused type 1 crucibles and in the case of the fragment from 29/01/10 (5) also some other organic material evidenced by the thin elongated impressions (up to 18mm long). The majority of the exterior convex surfaces are heavily abraded and orangey oxidised but the interiors tend to be of a darker and paler orange or a light to medium grey colour. On many of the fragments there appears to be a very thin layer (<3mm) of what looks like burnish or plaster that is smooth or low sandpaper rough in texture. None seem to be vitrified. The fragments from 12/02/10 (2) are definitely pottery as an almost complete pot was found at this location. This suggests that the other fragments are likely from pots too which would explain the lack of vitrification. However, the fact that they may be furnace lining fragments cannot be ruled out. Of special interest is that there are fine vertical linear striations on the interior (concave side) of the fragment from 25/02/10 (1). The fragment from 02/02/10 (7) has wider, shallow vertical impressions on the concave side. It also appears to be a rim fragment with one rounded edge but it has so vitrification meaning that it cannot be positively attributed to any metallurgical process.

29/01/10 (4)

29/01/10 (5)



02/02/10 (7)



05/02/10 (3)

12/02/10 (2)

25/02/10 (1)

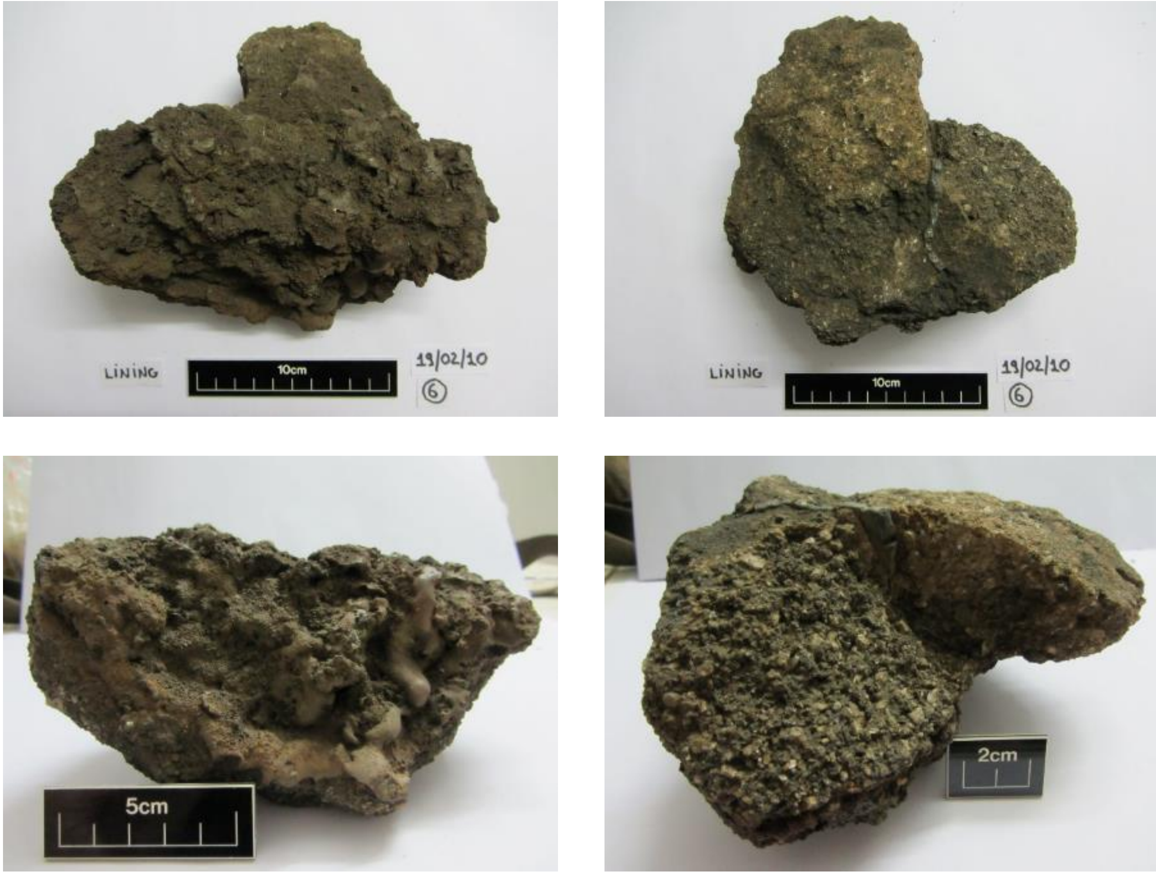
In addition to the non-diagnostic fragments placed in the four categories above, are five larger heavily vitrified curved fragments which have taken the shape of the bottom of the furnaces. These are found in locations 29/01/10 (2), 13/02/10 (4), 19/02/10 (6), 23/02/10 (9) and 25/02/10 (1). All except the fragment from 25/02/10 (1) seem to have a mixture of slag and vitrification on the interior surfaces. No original non-vitrified furnace lining remains on these fragments accept a thin coating of dark grey reduced clay on the exterior (convex) surface of the fragment from 23/02/10 (9). The fragments from 29/01/10 (2), 13/02/10 (4) and 23/02/10 (9) are very similar and comprise of a poorly preserved tuyere fragment at the top with a mixture of rough vitrification and slag below it. This vitrification and slag mixture shows signs of having been well molten with rounded protrusions and flows. However, most of these are broken revealing irregular and spherical porosity (mainly <12mm) as well as some charcoal impressions. This makes the surfaces very rough to the touch. What is interesting is that the vitrification and slag curve inwards (convex - like a bowl shape) on the undersides suggesting that a bowl shaped depression was present at the bottom of the furnaces. This is supported by the undulated texture on the underside of the fragment from 23/02/10 (9).

29/01/10 (2)

13/02/10 (4)

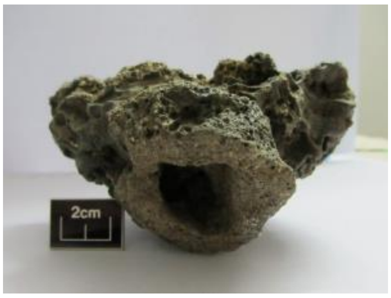
23/02/10 (9)

The fragment from 19/02/10 (6) is also interesting. It appears to be a section of a bowl shaped furnace base. This base is made out of very coarse clay dominated by quartz inclusions mainly <5mm but up to 8mm. It is almost perfectly convex on the underside and would have been circular in plan suggesting that it was lining a bowl shaped depression at the base of the furnace. On the top is vitrification and slag (with one magnetic patch) well-molten in appearance with rounded flows and trickles. It appears to have dribbled from the edge (where it has broken abruptly) of the bowl shaped clay base into a depression in its centre. This suggests that the furnace walls would have been placed around the clay base. This is supported by the fact that on its circumference is a flat platform where the elephant foot furnace type 1 bases found in the same location fit perfectly in width and curvature.



19/02/10 (6)

The fragment from 25/02/10 (1) is different as it is a lump of fully vitrified furnace lining. There is a circular (deformed) vitrified clay feature on one side with a large central hole. This must be the fully vitrified nozzle end of a tuyere which seems to have been blocked by the extensive melting of the furnace wall. The vitrification has a well molten appearance with rounded projections dominated by large charcoal impressions (mainly 30-40mm but up to 85mm). Many of these projections are broken revealing partially melted whitish-grey quartz crystals and many tiny spherical voids (<3mm) giving those parts a rough texture. The underside also has many charcoal impressions and well-rounded molten vitrification but its convex shape suggests that it solidified on a hard surface. This means that the bottom of the furnace would have had a shallow bowl shaped depression. The majority of the vitrification is black but there are some areas (especially the underside) with very dark green glassy vitrification. There are also two small (4-5mm) magnetic metallic prills on the underside of the fragment. The absence of diagnostic slag and the presence of these metallic prills suggest that this fragment resulted from the crucible steel process.



25/02/10 (1)

Appendix C.5 – Tuyeres

Many tuyeres and tuyere fragments were recovered during the 2010 Pioneering Metallurgy Project. Several types have been identified and this section will deal with the descriptions of these tuyere types. Very few tuyeres survive whole with the majority being fragmentary meaning that they could not be accurately measured, therefore, most diameter measurements were estimated from their surviving curvature. Table 1 below shows the weight in grams and general dimensions of the different types of tuyeres found in each location. All photographs relate to the text directly preceding them.

Table 1 - Weight in grams and general dimensions (mm) of the different types of tuyeres found in each location.

Location	Type (T)	Weight	No	Fabric	Inclu.	Length (max)	Inner dia.	Wall thick.
25/01/10 (6)	1	2756	9	M-C	Quartz <2 Add.clay	135mm (no rim)	22-30 noz 28-37 rim!	10-15
29/01/10 (1)	?(2)	279	4	M-C	Quartz <4mm	90mm (no noz)	60-70?	12-20
30/01/10 (1)	2?	42	1	L to M	Quartz <1mm	61mm (no noz)	?	11
30/01/10 (2)	2?	49	1	L to M	Quartz <1mm	47mm (no noz)	?	15
01/02/10 (1)	2?	190	1	L to M	Quartz <1mm	? (no ends)	50-60?	12
01/02/10 (6)	1	2072	12	M to C	Quartz Add. clay	122mm (no rim)	22-27 noz 25-32 rim!	7-13
02/02/10 (1)	1	3868	13+	M to C	Quartz <2 Add. clay	142mm (no rim)	21-25 noz 26-32 rim!	6-14 (to18)
02/02/10 (7)	2?	125	2	L to M	Quartz <1mm	? (no noz)	?	8-10
02/02/10 (8)	?(3)	544	Sev.	VC	Quartz <3mm	60mm (no rim)	20-25 noz 20-30 rim!	15-18
03/02/10 (4)	2?	57	2	M to C	Quartz <2mm	? (no noz)	?	11-14
03/02/10 (9)	2	35	1	M	Quartz <1mm	? (no noz)	40-50?	9-11
03/02/10 (11)	2	483	5	M to C	Quartz <3mm	78mm (no noz)	45-50 noz!? 70 rim?	9-12
03/02/10 (13)	2	34	1	M	Quartz <2mm	? (no noz)	60 noz!? 75 rim?	7-10
03/02/10 (14)	2	382	2	M	Quartz <2mm	? (no noz)	60 noz!? 75 rim?	7-10
03/02/10 (15)	2	998	7	M	Quartz <2mm	? (no noz)	40 noz!? 75 rim?	7-10
	?	80	1	M	Quartz <1mm	87mm (no ends)	70-80 rim?!	7-8
05/02/10 (1)	2	81	2	M	Quartz <2 up to 5	? v frag.	?	10-17
05/02/10 (3)	2	1896	12	M (one C)	Quartz <2 (one <4) to5	134mm	37 noz 75 rim	10-17
05/02/10 (4)	2	1034	9	M (one C)	Quartz <2 (one <4) to5	? v frag.	?	10-17

Location	Type (T)	Weight	No	Fabric	Inclu.	Length (max)	Inner dia.	Wall thick.
05/02/10 (7)	2	187	1	M	Quartz <2mm	90mm (no noz)	50 centre?	13-14
06/02/10 (2)	2?	197	6	M	Quartz <2 upto 5	? (no rim)	32 noz 40 rim!	11-17
	3	531	1					
08/02/10 (1)	2?	262	sev	M to C	Quartz <2mm	? v frag	?	10-17 one 28
	3?	650	2	M	Quartz <2mm	141mm (no noz)	60-70 mid? 120 rim?	23-33
	?	40	1	M	Quartz <2mm	48mm (no noz)	60 mid? 80 rim?	13-15
08/02/10 (2)	2?	20	1	M	Quartz <2mm	51mm (no ends)	?	9-11
08/02/10 (4)	2	13990	sev	M to C	Quartz <3mm	128/142mm (no rim but close) – 123mm (molten noz)	35-42 noz 75-80 rim!	11-22
	3?	840	1	M	Quartz <2mm	153mm (no ends)	80 mid?	37-50
08/02/10 (5)	?	40	1	M	Quartz <2mm	46mm (no ends)	?	16-18
08/02/10 (8)	2 + 2 long	1075	sev	M	Quartz <2mm	146 (no nozzle)	?	12-14
	2 thick	384	1	M	Quartz <2mm	?	?	17-23
08/02/10 (9)	1	2846	sev	M	Quartz <2mm	146mm (no rim)	27-31 noz 35-40 rim!	12-18
	2	3066	3	M	Quartz <3mm	115/132mm	33-38 noz 80 rim	12-19
08/02/10 (10)	2 + 2 thick	1720	4	M	Quartz <2mm	? v frag	?	?
09/02/10 (1)	1?	32	1	M	Quartz <1mm	? v frag	?	10-13
09/02/10 (2)	2?	102	3	L to M	Quartz <2mm	? v frag	?	10-13
	?(4)	210	3	L-M	Quartz <1mm	93mm (no ends)	42 mid? 50 rim?!	9-14
09/02/10 (5)	1	238	1	L to M	Quartz <3mm	90mm (no noz nor rim)	29 noz! 31 rim!	14-15
09/02/10 (6)	1	2243	8	M	quartz	168mm (no rim but close)	25-28 noz 30-34 rim!	8-14
	2	633	3	M	quartz	105mm (no noz)	30 noz 45 centre?	8-15
09/02/10 (7)	2?	4989	9	M	quartz	143mm (no rim but close)	25-30 noz 60 rim?	11-18
10/02/10 (1)	3?	341	1	F to M	Quartz <2 Char?	? (no noz)	37 noz! 45 rim	?
	3	3180	2	VC	Quartz 3-4mm	161mm (no rim)	44-46 tubular	23-33
11/02/10 (6)	2?	193	2	M	Quartz <2mm	? v frag (no ends)	35-40 close to rim!?	8-10
12/02/10 (1)	2	419	sev	L	Few Quartz High organic	<65 v frag	30-40!?	9-13
	2?	16	1	M	Quartz <1 Organic?	? v frag (no ends)	?	8
	4	545	sev	F to L	Vfew quartz Organic?	<70mm (no rim)	25-28 noz 30-32 rim!	4-9
			1	F to L	Vfew quartz Organic?	160mm (no rim)	22 noz 23 rim!	3-8
12/02/10 (3)	3	718	3	F to L	Vfew quartz	? frag	40 tubular!?	25-38

Location	Type (T)	Weight	No	Fabric	Inclu.	Length (max)	Inner dia.	Wall thick.
					High organic			
12/02/10 (6)	4	144	1	F	Vfew quartz Organic?	61mm (no rim)	27 noz 30 rim!	9-11
12/02/10 (4)	3	616	2	F to L	Vfew quartz High organic	? frag	40 tubular!?	25-38
13/02/10 (1)	2	1964	sev	M – M to C	Quartz <3 Upto 7	128mm (no noz)	80 rim? 50 centre? 40-45 noz?	11-17
13/02/10 (2)	2?	631	sev	M	Quartz <2mm	? frag	80 rim? 40-45 noz?	11-17
13/02/10 (3)	2	320	1	M	Quartz <3mm	92mm (no noz)	80 rim? 50 mid ?	<16
13/02/10 (4)	2?	294	sev	M	Quartz <2mm	? frag	80 rim? 40-45 noz?	11-17
		In furn wall	1			? frag	?	?
13/02/10 (13)	2	553	1	M	Quartz <2mm	140mm (no noz nor rim but close)	50 noz! 80-85 rim!	8-13
13/02/10 (15)	2?	20	1	M	Quartz <2mm	? very frag (no ends)	?	12-14
15/02/10 (2)	2	275	7	M	Quartz <2mm	54mm (no ends)	40-70 mid?	8-14
15/02/10 (3)	2	866	3	M	Quartz <2mm	155mm	45 noz 79-82 rim	12-14
15/02/10 (4)	3	212	1	M	Quartz <3mm	? frag (no rim)	60?	37
16/02/10 (2)	2?	348	3	M	Quartz <3mm	68mm (no ends)	80-90 rim?	10-20
16/02/10 (3)	2	397	1	M	Quartz <3mm	80mm (no noz)	40 centre? 60-70 rim?	10-20
16/02/10 (4)	2	276	5	M	Quartz <3mm	? (no noz)	80-90 rim?	10-21
16/02/10 (5)	2	384	6	M	Quartz <3mm	? frag	80-90 rim?	10-20
16/02/10 (6)	2 long	650	4	M	Quartz <2 Upto 6	148 (no noz nor rim)	30 noz!? 80 rim!?	14-18
17/02/10 (2)	2	129	1	M to C	Quartz <2 Upto 5	92mm (noz heavy vitrification)	70 centre? 80-90 rim?	10-15
	2?	360	8	M	Quartz <3mm	62mm (no noz)	70 rim? 40 noz?!	10-20
	3?	160	1	M	Quartz <2mm	91mm (no ends)	?	32
17/02/10 (3)	2?	312	5	M	Quartz <2 Upto 5	110mm (no noz)	70-80 rim?	12-20
	3?	114	2	M	Quartz <2 Upto 5	? v frag	40-50 cent? Tubular?	18-26
18/02/10 (1)	2?	50	1	M	Quartz <2 up to 6mm	58mm (no ends)	50 mid?	13-18
18/02/10 (3)	2?	50	2	M	Quartz <2mm	41 (no ends)	40-50 mid?	12-19
18/02/10 (4)	2?	310	8	M	Quartz <2 Up to 5	60mm (no ends)	80 rim?! 60 mid?!	10-17
18/02/10 (6)	2	542	sev	M to C	Quartz <2 Upto 3	? frag but seem short	50-60 cent? 70-80 rim?	11-18
	2?	In furn wall	1	M	Quartz 2mm	? only part of noz	?	?
19/02/10 (3)	2	5950	lots	M	Quartz <2mm	122mm one well preserved expl	40 noz 90 rim	11-15

Location	Type (T)	Weight	No	Fabric	Inclu.	Length (max)	Inner dia.	Wall thick.
					Upto 7	90-143mm rest of frags	35-40 noz 65-90 rim	9-19
		In furn wall	1			? measurements not taken	?	?
	?	50	1	M	Quartz <2mm	53mm (no ends)	?	8-9
19/02/10 (4)	2	700	12	M	Quartz <2mm	82mm (no noz)	50 noz?! 90 rim?	8-15
19/02/10 (5)	2?	1544	9	M	Quartz <2mm	95 (no ends)	70 rim?!	10-14
19/02/10 (6)	?	40	1	M	Quartz <2mm	63mm (no ends)	70 rim?!	9-13
21/02/10 (3)	3?	302	1	L silty	Few quartz <3mm	? v frag	?	41
21/02/10 (7)	?	30	1	M	Quartz <2mm	45mm (no rim)	30 noz?!	10-13
21/02/10 (9)	1	362	1	M	Quartz <2 Upto 5	138mm (no rim)	13 noz 30 rim!	11-13
22/02/10 (1)	2	80	1	M	Quartz <2mm	61mm (no noz)	70 rim?	10-14
	?(4)	90	2	L	Quartz <1 organic?	78mm (no rim)	35 noz?!	9-11
22/02/10 (3)	?	320	2	M	Quartz <2mm	76mm (no ends)	40 noz?! 60 mid?	11-13
23/02/10 (1)	?	113	2	L to M	Quartz <2mm	41mm (no ends)	?	10-15
23/02/10 (2)	2?	280	8	M	Quartz <2mm	47mm (no ends)	75 rim?!	11-16
23/02/10 (3)	2	680	2	L to M	Quartz <2mm	100mm (damaged rim/noz)	46 noz!? 80-90 rim?	10-15
23/02/10 (4)	?(1)	605	1	M	Quartz <3mm	? (no ends)	35 noz! 50 rim!	14-19
	?	180	3	M	Quartz <3mm	65mm (no ends)	50 mid?	15-17
23/02/10 (5)	?	130	2	M	Quartz <2mm	60mm (no ends)	50 noz?! 70-80 mid?	13-18
23/02/10 (6)	?	40	1	M	Quartz <2mm	56mm (no rim)	?	17
23/02/10 (9)	2 long	881	1	M	Quartz <2 Upto 4	181mm (no noz)	39 noz! 85 rim	12-14
	2	In 3 furn walls	3			115mm (no rim but close) rim no noz on other ex	37 noz 52 rim! 74rim	10-15
	2 + 2 thick + ?	In 1 furn wall	7+			? many stacked frags in wall	?	?
24/02/10 (1)	2	166	8	M	Quartz <2mm	47mm frag (no noz)	90 rim?	10-14
24/02/10 (3)	2	899	16	M to C	Quartz <5 up to 16	81mm frag (one end missing)	70-80 rim?	8-19
	3?	149	1	C	Quartz <4 Upto 9	<80? frag (no ends)	?	21-23
24/02/10 (4)	2	415	3	M	Quartz <2mm	? frag	?	8-13
25/02/10 (1)	?(1)	1480	1	M	Quartz <2mm	130mm (no rim)	30 noz 40 rim!	16-21
	?	In furn wall	1	?	?	? v frag/impression	?	?

Location	Type (T)	Weight	No	Fabric	Inclu.	Length (max)	Inner dia.	Wall thick.
	2?	410	4	M	Quartz <2mm	103mm (no ends)	50 mid?	12-18
25/02/10 (2)	2?	495	2	M	Quartz <2mm	80mm (no rim)	?	12-13
25/02/10 (3)	?	110	2	M	Quartz <2mm	61mm (no ends)	50 mid?	13-16
25/02/10 (8)	2	65	3	L to M	Quartz <1mm	<50 frag	?	8-13
26/02/10 (1)	2	84	1	M	Quartz <2mm	95mm (no noz)	40 noz!? 60-70 rim?	7-12
	?(2)	30	1	L to M	quartz	30mm frag (no noz)	60-70 rim?	15
	2?	180	5	M	Quartz <2mm	60mm (no ends)	40 mid?	10-19
26/02/10 (3)	2	1625	sev	M	Quartz <2mm	112mm (no noz)	40 noz!? 80 rim?	10-16
26/02/10 (5)	2?	151	3	M	Quartz <2mm	<70mm frag	40 noz!? 70-80 rim?	?
26/02/10 (5/6)	2	2723	6	M	Quartz <2mm	155mm	30 noz 80-90 rim?	10-21
	?(1)	834	1	M to C	Quartz <2mm	167mm (no ends)	30 noz!	?
26/02/10 (7)	?	60	3	M	Quartz <2mm	42mm (no ends)	?	11-16
26/02/10 (8)	2?	20	2	M	Quartz <2mm	V frag <45mm	?	?
	?(2)	25	1	L to M	quartz	Frag (no noz)	60-70 rim?	13
27/02/10 (3)	2?	100	2	M	Quartz <2mm	60mm (no ends)	?	9-14
27/02/10 (4)	2	In furna wall	1	M	Quartz <2mm	150mm	35 noz 70 rim?	10-12
	2	1310	2	M	Quartz <2mm	145	30-34 noz 65 rim	13-17
27/02/10 (5)	1	230	1	M	Quartz <2mm	121mm (no rim)	24 noz 26 mid?	9-13
27/02/10 (6)	2	674	1	M	Quartz <2mm	103mm (rim damaged)	39 noz 75 rim?	13-19
	2 thick	279	1	L to M	Quartz <1mm	90mm (no noz)	80 rim?	18-25
	2?	280	6	M	Quartz <2 up to 6	66mm (no noz)	40 noz?! 60-70 rim?!	10-18
27/02/10 (7)	2?	201	4	M	Quartz <2mm	? v frag (no ends)	?	<16
	2	In furn wall	1			122mm (no noz)	40 noz!? 90 rim?	10-13
	2	670	2	M (M-C)	Quartz <2mm	117mm (molten noz)	36 noz 80 rim	12-17

Key:
F – fine **L** – low coarse **M** – medium coarse **C** – coarse **VC** – very coarse
noz – tuyere nozzle **rim** – tuyere rim **!** – measurement closest to end (that does not survive)
? – estimated measurement (incomplete circumference)
? – too fragmentary to provide data
Add. clay – additional clay lump placed on exterior surface of tuyere
Sev – several
Frag – fragmentary (no complete circumference and at least one end missing)
V frag – very fragmentary (no complete circumference and both ends missing)

Appendix C.5.1 – T1

Characteristic features	Small inner diameter; very slight inner diameter taper towards nozzle; thin to medium wall thickness; no rim flare; added clay lump on exterior tuyere surface
Fabric	Medium coarse to coarse dominated by quartz temper
Size range	Up to 142mm in length (incomplete); 21-30mm inner diameter at nozzle; 25-37mm inner diameter at closest surviving part to rim; 7-15mm wall thickness
Locations in which found	25/01/10 (6); 01/02/10 (6); 02/02/10 (1); 08/02/10 (9); 09/02/10 (1) (5) (6); 21/02/10 (9); 27/02/10 (5)

Many well preserved type 1 tuyere fragments were recovered with complete circumferences from 25/01/10 (6), 01/02/10 (6), 02/02/10 (1), 08/02/10 (9), 09/02/10 (1) (5) (6), 21/02/10 (9) and 27/02/10 (5) but unfortunately no fragment survives whole with the rim end missing on the majority. Nevertheless, this allowed for more accurate measurements to be taken. There were also several small, less diagnostic fragments which have been characterised as the same type due to their similar fabrics, size and curvature. The major characteristics of this tuyere type are their small inner diameters which taper very slightly towards the nozzle end; their thin to medium wall thickness; the fact that there is no evidence of a rim flare and the best preserved examples have an added clay lump on their exterior surface. Their sizes range from 21-31mm nozzle inner diameter, 25-40mm closest surviving part to rim inner diameter, 7-18mm wall thickness and up to 146mm in length (although incomplete). The fragment from 21/02/10 (9) has an internal diameter at the nozzle of 13mm but this may be due to the fact that it is heavily vitrified and some of the vitrification as melted onto the nozzle opening. The fragment from 09/02/10 (5) and one from 09/02/10 (6) have both ends missing (neither have vitrification) but their general shape and size seem identical to the body sections of the better preserved examples. The fragment from 09/02/10 (1) is very fragmentary with no ends nor complete circumference but its shape and size also points to a similar tuyere type.

As all other tuyeres they seem to have been manufactured by moulding clay around a cylindrical object. The interiors are smooth with faint horizontal (in direction of circumference) slip marks suggesting that the inner mould (most likely a shaped wooden branch/stick) was removed while the clay was still partially wet while the exterior is uneven as if moulded by hand. These exterior depressions are horizontal and elongated about the size of fingers. Their fabrics are medium to coarse dominated by small quartz grains mostly <2mm in size. They vary in colour from a brownish oxidised orange to dark grey reduced. The inner surfaces and rim ends tend to be orangier in colour while the nozzle ends are dark grey to black and heavily vitrified.

Of special interest are that six fragments from 25/01/10 (6), six from 01/02/10 (6) and five from 02/02/10 (1) have large lumps of clay on one side of their exterior surfaces close to their nozzle ends. The majority of the other tuyere fragments that do not have a clay lump have signs that they once had one with darker patches on their surfaces. This clay is heavily vitrified but the vitrification does not extend further up the tuyeres. This means that it was added prior to the firing of the furnace. Some of these added lumps of clay (particularly from 25/01/10 (6)) have small impressions which look like finger marks suggesting that the clay was moulded onto the tuyeres. It may have been added to help keep the tuyeres in place as well as maybe protect the nozzle ends from melting in the high temperatures. The added clay varies in thickness from about 20 to 38mm and all have abrupt breaks at the highest level of vitrification suggesting that they must have been in contact with (or indeed have been part of) the furnace wall. The vitrification is black with different shades of grey and is rough with small protrusions of material. There are also some whitish grey inclusions which are undoubtedly quartz grains. The breaks on these clay lumps reveal that the vitrification is only on the surface with more reduced dark grey to black clay underneath. This fact, as well as evidence of finger marks suggests that it was intentionally added as opposed to have melted onto the tuyeres from the furnace wall. The clay fabrics appear to be different from the tuyere wall fabrics. The additional clay on the tuyeres from 25/01/10 (6) are fine to medium coarse with few quartz grain inclusions mainly <3mm while the clay fabrics from 01/02/10 (6) and 02/02/10 (1) are coarser with many medium sized quartz crystals mainly <4mm but up to 8mm. In a few examples the clay gets more porous close to the vitrification. The coarser clay on the tuyeres from 02/02/10 (1) is very similar to clay found adhering to slag fragments in the same location. Of interest is that one of the tuyeres in 01/02/10 (6) has a pottery sherd inclusion within the added clay lump matrix meaning that they may have recycled old ceramics to use as grog.

25/02/10 (6)

25/02/10 (6)

25/02/10 (6)

01/02/10 (6)

01/02/10 (6)

01/02/10 (6)

01/02/10 (6)

02/02/10 (1)

02/02/10 (1)

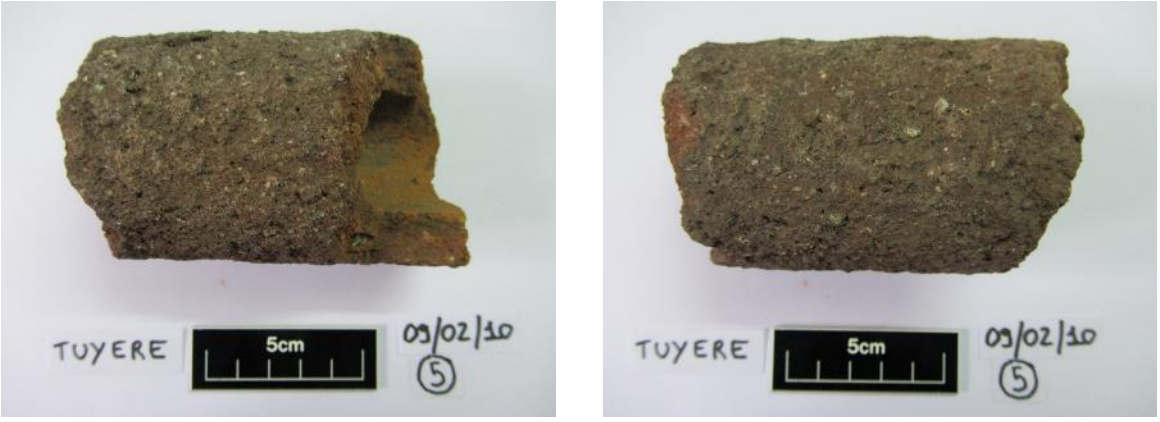
The vitrification on the fragments from 08/02/10 (9) and 09/02/10 (6) is slightly different. The vitrification on the fragments from 08/02/10 (9) is thin (up to 14mm) while the vitrification on the fragments from 09/02/10 (6) tends to be thicker (up to 30mm) with increased porosity just below the surface. Most of the vitrification has some reduced clay underneath meaning that a layer of clay was added at the nozzle end, perhaps to help positioning or to protect the tuyere from melting. All the vitrification is broken close to the nozzles suggesting that the tuyeres were unlikely to have projected more than 100mm inside the furnace. The vitrification is of the usual medium rough, well molten looking type with greyish-white partially melted quartz crystals visible on the surface. Some of the fragments from 09/02/10 (6) have rougher and more agitated vitrification. The clay added to the outside of the tuyeres from 08/02/10 (9) is coarser than the tuyere fabric with lots of small quartz crystals (mainly <4mm) while the clay from 09/02/10 (6) is mainly medium coarse with some quartz inclusions, similar to the clay lining found in the same location. The fragment from 27/02/10 (5) and one from 25/01/10 (6) do not have any adhering clay remaining and may not have had any but their nozzle ends are vitrified. This vitrification is thin (<5mm) and appears to have come from the tuyere fabric itself reaching approximately 50-60mm up the tuyeres.

Of special interest is that the two largest examples from 09/02/10 (6) have some dark brownish-red patches which are magnetic suggesting that these tuyeres were used for iron production as opposed to crucible steel production. There is one fragment with furnace lining stuck to its sides and a broken tuyere fragment resting just outside the more intact tuyere suggesting that they may have been replaced when needed. There is another which has a blocked nozzle where the vitrification or slag has covered the end.

It is also worth noting that the vitrification on the tuyere nozzles appears to be at an angle. The vitrification on one side goes further up the tuyere than on the other suggesting that the tuyeres were placed in the furnace wall at an angle. The vitrified additional clay lump is always on the side with the most vitrification. Assuming that the tuyeres were angled with the nozzle facing down into the furnace these clay lumps were added to the top of the tuyeres. This proposed orientation of the tuyere (nozzle pointing down into the furnace) is the most likely as the more rounded flows of vitrification seen on some tuyere nozzles seem to have melted in that direction.

08/02/10 (9)

08/02/10 (9)



09/02/10 (5)

09/02/10 (6)

09/02/10 (6)

09/02/10 (6)

09/02/10 (6)



27/02/10 (5)

Appendix C.5.2 – T2

Characteristic features	Medium to large inner diameters; heavily tapering inner diameter towards nozzle; medium wall thicknesses; flaring rim
Fabric	Mostly medium coarseness with quartz inclusions <2mm. Some medium to coarse with quartz inclusions <5mm
Size range	Complete fragment 92-155mm (one incomplete up to 181mm) in length; 30-45mm inner diameter at nozzle; 65-90mm inner diameter at rim; 7-20mm wall thickness (most between 10-15mm and two fragments 17-25mm)
Locations in which found	Definite: 02/02/10 (9), 03/02/10 (9) (11) (13) (14) (15), 05/02/10 (1) (3) (4) (7), 08/02/10 (4) (8) (9), 09/02/10 (6) (7), 12/02/10 (1), 13/02/10 (1) (3) (13), 15/02/10 (2) (3), 16/02/10 (3) (4) (5) (6), 17/02/10 (2), 18/02/10 (6), 19/02/10 (3) (4), 22/02/10 (1), 23/02/10 (3) (9), 24/02/10 (1) (3) (4), 25/02/10 (8), 26/02/10 (1) (3) (5/6), 27/02/10 (4) (6) (7) Probable: 30/01/10 (1) (2), 01/02/10 (1), 02/02/10 (7), 03/02/10 (4), 06/02/10 (2), 08/02/10 (1) (2), 11/02/10 (6), 12/02/10 (1), 13/02/10 (2) (4) (15), 16/02/10 (2), 17/02/10 (2) (3), 18/02/10 (1) (3) (4), 19/02/10 (5), 23/02/10 (2), 25/02/10 (1) (2), 26/02/10 (1) (5) (8), 27/02/10 (3) (6) (7).

Type 2 is by far the most common type of tuyere. These were recovered from the majority of the metallurgical locations. There is a significant level of variation in size and wall thickness but the major morphological characteristic which defines this type is their flaring rim and heavily tapering inner diameters towards the nozzle end. Very few examples survive whole but many have enough circumference remaining and at least one surviving end (rim or nozzle) to allow identification. Some locations have less well preserved fragments which are to a certain extent non-diagnostic but their general shape and fabric (or association with better preserved examples) make them likely to have been of this flaring type.

The tuyeres appear to have been built in the same way by moulding clay around an inner cylindrical mould. Due to the tapering inner diameters of the tuyeres this mould was likely to have been almost conical. The interior surfaces of the tuyeres have the characteristic horizontal slip marks (striations) and uneven exterior surfaces. A few of the better preserved examples have some vertical (aligned to the tuyere length) slip marks on one side suggesting that the inner mould was removed while the clay was still partially wet. The inner mould may have been moistened or covered in slip to facilitate removal of the tuyere. The flaring rims were likely to have been shaped by hand as the wall thickness tends to be thinner and there are usually less or no slip marks on the interior surface close to the rim. The rim edges are either rounded or flattened (angular).

The best preserved examples are found in 02/02/10 (9), 03/02/10 (9) (11) (13) (14) (15), 05/02/10 (1) (3) (4) (7), 08/02/10 (4) (8) (9), 09/02/10 (6) (7), 12/02/10 (1), 13/02/10 (1) (3) (13), 15/02/10 (2) (3), 16/02/10 (3) (4) (5) (6), 17/02/10 (2), 18/02/10 (6), 19/02/10 (3) (4), 22/02/10 (1), 23/02/10 (3) (9), 24/02/10 (1) (3) (4), 25/02/10 (8), 26/02/10 (1) (3) (5/6) and 27/02/10 (4) (6) (7). These reveal that the tuyeres varied slightly in inner diameter and in length. The most complete examples show that they were between 92-181mm in length although the nozzle ends are often very vitrified and it is not possible to judge how much of the tuyere melted in the furnace. Their inner diameters vary from 65-90mm at the rim end to 30-45mm at the nozzle end. Their fabrics are mostly medium coarse with quartz inclusions <2mm but some are medium to coarse with quartz inclusions up to 5mm in size. The main exception are the fragments from 12/02/10 (1) which have fabrics of low coarseness with a significant proportion of organic inclusions. Their wall thicknesses vary from 7-20mm with most between 10-15mm. Two fragments from 08/02/10 (8) and 27/02/10 (6) have significantly thicker walls between 17-25mm. Although their complete circumference does not survive their remaining curvature shows similar inner diameters as the other thinner walled examples. There also seems to be a long version of this type represented in 08/02/10 (8), 16/02/10 (6), 23/02/10 (9). These have flaring rims like the others with a heavily tapering inner diameter close to the rim but they seem longer with a more gradual inner diameter taper in the body towards the nozzle end. None of these survive whole with the nozzle end missing on all fragments. No vitrification is present meaning that it may have broken off or perhaps these tuyeres were not used. If they have been used they would either have protruded considerably on the exterior of the furnace or they were used in thicker furnace/hearth walls (perhaps for a different technology – smithing?).

08/02/10 (8)

27/02/10 (6)

08/02/10 (8)

23/02/10 (9)

The tuyeres are mainly oxidised orange in colour (sometimes slightly reddish) on most of their surface but especially close to the rim ends and on the interior surfaces. They tend to get darker from light to dark grey in colour closer to the nozzle ends suggesting that these parts have become reduced and were likely to have been subject to higher temperatures.

Many of the tuyere fragments also have vitrification at their nozzle ends. This vitrification is similar on most examples. It is usually dark grey to black with well molten rounded features and varying proportions of light grey partially melted quartz inclusions. The surfaces range from smooth to medium rough (medium sandpaper rough when there are more quartz inclusions) with some rounded projections of material suggesting that some of it had partially flowed. Some fragments appear to have more agitated and slightly rougher vitrification while a few others have almost smooth glassy black vitrification. In some cases this vitrification has dripped partially covering the nozzle opening. Two fragments, one fragment from 09/02/10 (6) and one from 09/02/10 (7) have a blocked nozzle end which would have rendered the tuyeres useless. Some of the vitrification has charcoal impressions and more rarely dark brownish-red (rusty) patches that are magnetic suggesting that this type was more likely used for iron smelting than crucible steel production. On many there is also spherical and globular porosity underneath the vitrified surface. On most fragments the vitrification appears to have broken off abruptly (in a neat straight break) suggesting that this was likely to have been where the furnace wall started. On the better preserved examples with the majority of their circumferences remaining it is clear that the vitrification is not even on all sides of the tuyeres. The vitrification is at an angle reaching up the tuyere further on one side than the other. This suggests that the tuyeres were placed at a downwards angle in the furnace wall. On most small fragments the vitrification is thin (not usually more than 15mm) but on others there are remains of clay adhering to the exterior surfaces of the tuyeres which must have been part of the furnace wall/lining.

03/02/10 (11)

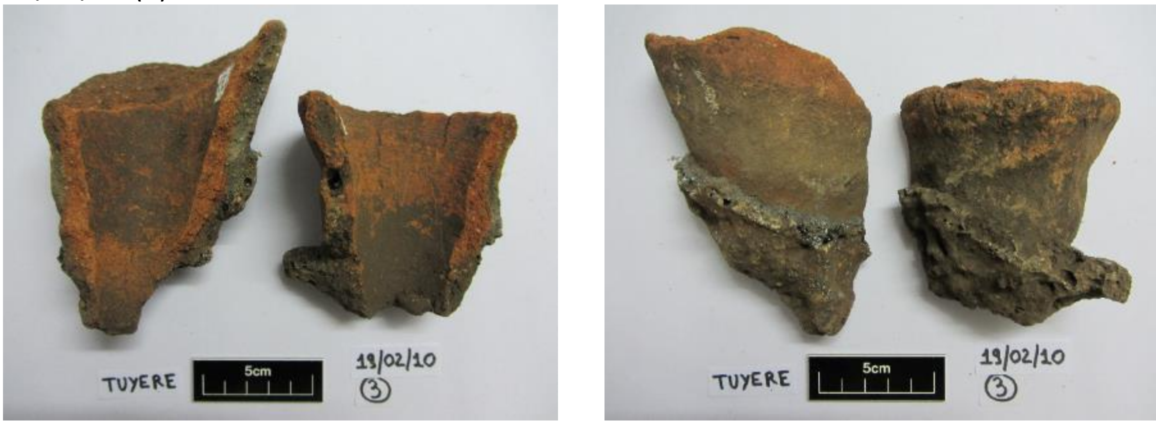
05/02/10 (3)

08/02/10 (9)

09/02/10 (7)

13/02/10 (1)

19/02/10 (3)



19/02/10 (3)

27/02/10 (4)

These are found in locations 03/02/10 (11) (14), 05/02/10 (3), 08/02/10 (4) (9), 09/02/10 (7), 13/02/10 (1) (3) (4), 16/02/10 (2) (3) (5), 18/02/10 (6), 19/02/10 (3) (4), 23/02/10 (3), 24/02/10 (3) (4), 26/02/10 (3) (5/6) and 27/02/10 (6). For the most part the adhering furnace wall is non-diagnostic having lost its original exterior surface and base but the fabrics tend to be similar (medium to coarse quartz rich clay) to other refractory material (furnace wall) found in the same or associated (very close) locations. In a few instances the furnace wall adhering to the tuyeres appears to have coarser fabric than the refractory fragments found in the same locations. This may be because not all furnace wall types were recovered at those locations or it may indicate that a different clay was used to keep the tuyeres in place and seal them in the furnace wall. There is ethnographic evidence for such practices. The adhering furnace wall is mainly dark grey reduced in colour but there are some oxidised orangey brown areas on better preserved examples closer to the rim end of the tuyeres (the closest parts to the exterior surface of the furnace). The interior surfaces of the walls are heavily vitrified and appear to be fused to the tuyeres. On most examples this wall vitrification layer gets thinner towards the nozzle ends of the tuyeres suggesting that the majority of the vitrification on the tuyeres came from the melting of the furnace wall. However, sometimes a thin (<10mm) layer of heavily reduced non-vitrified clay remains underneath the vitrification almost to the nozzle suggesting that a fine layer of clay may have been placed on some tuyeres either to help them stay in place or to protect them from the high temperatures.

The fragments with the best preserved adhering wall are found in 08/02/10 (4) (9), 19/02/10 (3) and 27/02/10 (6). They reveal that the majority of the tuyeres were placed at a 25-40 degree angle with the nozzle facing down into the furnace. The only exception is one fragment from 08/02/10 (4) which appears to have been placed almost perpendicularly in the furnace wall. Some tuyeres also seem to have been placed in the furnace wall at a slight sideways angle suggesting that some furnaces may have had more than one tuyere. Since all the best preserved tuyere fragments have heavy vitrification at the nozzle end, it is not possible to estimate how much was lost to melting but in their current state they appear to have protruded 35-100mm inside the furnace. Their rim ends appear to have been almost flush with the exterior of the furnace wall protruding a maximum of 30mm. The best preserved fragments from 08/02/10 (4) show that the tuyeres were placed close to the base of the furnace wall (<100mm) and that the nozzle ends were either projecting (inside) below or at the same level as the furnace base. This suggests that the base of the furnace was not flat and a purposely made central depression must have been made at the base of the furnace. This is supported by the fragment from 08/02/10 (4) where the wall vitrification protrudes below the flat furnace base.

08/02/10 (4)

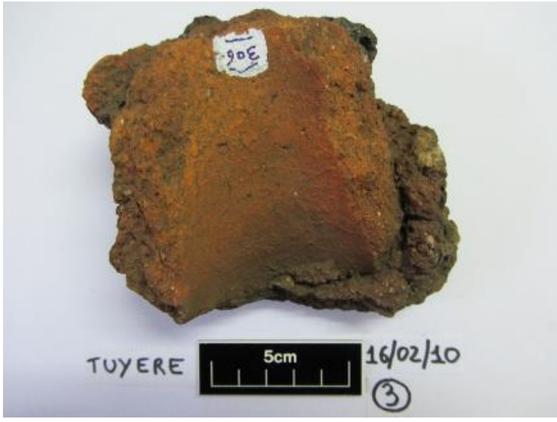
27/02/10 (6)



08/02/10 (4)

Two tuyere fragments with adhering wall, one from 13/02/10 (1) and another from 16/02/10 (5) show evidence of having been replaced as both have an additional tuyere fragment imbedded in the furnace wall next to the better preserved tuyere. It is likely that the furnace was re-used and that the tuyere needed replacing either because too much of it had melted or the nozzle end had been blocked as seen at some locations. Another tuyere fragment from 16/02/10 (3) appears to have been reused as there is a layer of non-vitrified clay above the tuyere vitrification.

16/02/10 (5)



16/02/10 (3)

Of special interest are tuyere fragments embedded in larger furnace wall fragments. Since these primarily consist of furnace wall they were weighed in that material category but they provide a lot of information about the placement of the tuyeres. There is one furnace wall fragment from 13/02/10 (4), 18/02/10 (6), 19/02/10 (3), 27/02/10 (4), 27/02/10 (7) and four from 23/02/10 (9). All embedded tuyeres are of the same type as above except maybe one from 23/02/10 (9) which will be discussed in more detail below. The fragment from 18/02/10 (6) is very fragmentary meaning that the information it provides is limited. The others on the other hand are better preserved (most curved with bases) and show that the tuyeres, like mentioned above, were placed in the furnace wall at an approximate 30-40 degree angle and 30-60mm from the base (on the exterior). The nozzle ends protrude up to 70mm inside the furnace while the rim ends are almost flush with the exterior wall. All of these furnace wall fragments (except the same one from 23/02/10 (9)) appear to have been either part of the elephant foot or straight wall type 1 furnace lining (see chapter 5.2.1).

These will be discussed in more detail in the furnace wall section. Of importance though is that the furnace wall from 13/02/10 (4) and one from 23/02/10 (9) have heavily melted and solidified, forming a curved (convex) base protruding into the inside of the furnace. This once again reinforces the idea that the furnaces had a purposely dug shallow depression at their base. Both fragments have agitated black vitrification with many charcoal impressions. It is likely that this vitrification is mixed with furnace slag.

13/02/10 (4)

19/02/10 (3)

23/02/10 (9)

23/02/10 (9)

27/02/10 (4)

27/02/10 7)

The largest fragment from 23/02/10 (9) is very different from any of the other furnace walls with imbedded tuyeres. It is a large base fragment and is discussed in more detail in the furnace wall section (see chapter 5.2.4). In the middle of the fragment on the base is a thin walled tuyere. This tuyere touches the base meaning that it must have rested on the ground as there is no clay between it and the base. It is about 115mm in length but the rim end is missing suggesting that it would have been longer. Its inner diameter is pretty consistent being 37mm at the closest end to the rim to 36mm at the nozzle. This means it is unlikely to have been a flaring type 2 but more of a small to medium sized tubular non-diagnostic tuyere. The nozzle protrudes about 50mm from the vitrified furnace wall and the tuyere was placed perpendicularly to the furnace wall with no major angle. Of special interest is the composition of the ceramic wall. Since the original outer surface is broken it reveals many curved fragments of tuyeres (that appear to have been used). These have been stacked with the convex side facing up but there is one fragment which is convex side down (all appear to be about ⅓ of their original circumference). These tuyeres, by majority, appear to be of the flaring type 2 kind with medium sized walls but there are some thicker fragments that have less rim flare. It is possible that these were tuyeres that broke during firing and that were replaced but the large quantity of them (at least 7 fragments) would suggest that used tuyeres were purposely built into this wall. This would mean that it was a small furnace wall built by re-using old tuyeres and since it has no evident curvature it was most probably used for smithing to support the heaped charcoal.

23/02/10 (9)

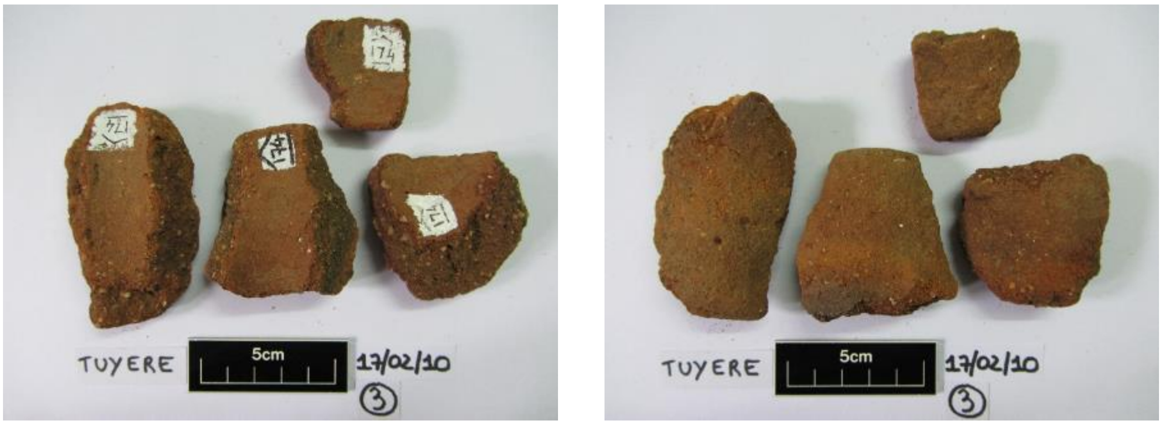
The more fragmentary examples are found in 30/01/10 (1) (2), 01/02/10 (1), 02/02/10 (7), 03/02/10 (4), 06/02/10 (2), 08/02/10 (1) (2), 09/02/10 (7), 11/02/10 (6), 12/02/10 (1), 13/02/10 (2) (4) (15), 16/02/10 (2), 17/02/10 (2) (3), 18/02/10 (1) (3) (4), 19/02/10 (5), 23/02/10 (2), 25/02/10 (1) (2), 26/02/10 (1) (5) (8), 27/02/10 (3) (6) (7). These are non-diagnostic for the most part but their curvature indicates that they may have been type 2 flaring rim tuyeres. Their wall thicknesses and fabric as well as their general dimensions and vitrification are very similar to the type 2 tuyeres discussed above.

30/02/10 (1)

02/02/10 (7)

08/02/10 (1)

16/02/10 (2)



17/02/10 (3)


18/02/10 (4)

27/02/10 (7)

Appendix C.5.3 – T3

Characteristic features	Medium to thick walls; medium to large inner diameter; no or very little inner diameter taper to nozzle (almost tubular)
Fabric	Varies from low coarseness to very coarse with mostly a quartz temper (<2mm but up to 5mm)
Size range	Length up to 161mm (incomplete), inner diameter range from 37-60mm, wall thickness mainly 18-50mm
Locations in which found	Definite: 06/02/10 (2), 10/02/10 (1), 12/02/10 (3) (4), 15/02/10 (4) Probable: 08/02/10 (1) (4), 17/02/10 (2) (3), 21/02/10 (3), 24/02/10 (3)

Type 3 tuyeres are found in locations 06/02/10 (2), 10/02/10 (1), 12/02/10 (3)(4), 15/02/10 (4) and also perhaps in 08/02/10 (1) (4), 17/02/10 (3), 21/02/10 (3) and 24/02/10 (3). These are generally in a poor state of preservation with only small fragments remaining and with the exception of a few tuyere fragments from 06/02/10 (2), 10/02/10 (1) the majority do not have a complete circumference. They differ from the other two types by having thicker walls between 18-50mm, very little or no internal diameter taper towards the nozzle end (tubular) and a medium to large inner diameter between 37-60mm with most around the 40mm mark. All fragments except one from 10/02/10 (1) are missing the rim ends but the fact that the width of the tuyeres do not seem to widen significantly towards the rim suggests that they were likely to have had a straight walled, non-flaring rim end. Indeed the rim fragment from 10/02/10 (1) with complete circumference shows no major flare. Its inner diameter tapers slightly from the rim end (45mm) to the furthest surviving part close to the nozzle end (37mm) but the walls remain almost straight with an even thickness along the length of the tuyere. The rim appears to have been flattened at the end with the corners rounded slightly.

All the tuyere fragments of this type were been built in the same way as all other tuyeres. The vertical slip marks on the interior surfaces and the uneven outer surfaces suggests that they were moulded around a cylindrical object. This was most likely a shaped piece of wood/branch. A fragment from 12/02/10 (3) has horizontal striations going down the inner surface which look like wood grain imprints, so at least in this case it is likely that it was moulded around a piece of wood.

Their clay fabrics vary significantly from low coarseness to very coarse. The ones from 06/02/10 (2), 08/02/10 (1) (4), 15/02/10 (4) and 17/02/10 (2) (3) have medium coarse fabrics with quartz temper mostly <2mm but up to 5mm; one fragment from 10/02/10 (1) and the one from 21/02/10 (3) are of low coarseness with some smaller and sparser quartz temper <2mm. The two largest fragments from 10/02/10 (1) and the one from 24/02/10 (3) are coarse to very coarse dominated by quartz inclusions around 4mm but up to 9mm. The fragments from 12/02/10 (3) (4) are very different being fine to low in coarse and dominated by large proportion of organic inclusions. These are seed-like elongated voids/impressions which may have been rice/millet husks or some sort of cereal grain. Since the nozzle ends survive better, the majority of the fragments are of a medium to dark grey reduced colour but they do have some oxidised orangey clay on the internal surfaces and further away from the nozzle ends.

The majority of the fragments with surviving nozzles have some vitrification. On the fragments from 06/02/10 (2), 15/02/10 (4) and one example from 10/02/10 9 (1) the vitrification is only present on the extremity of the nozzle ends suggesting that they did not protrude much into the furnace (<100mm). The fragments from 12/02/10 (3) (4), 17/02/10 (3), 21/02/10 (3) and 24/02/10 (3) do not have any ends surviving but all have some thin vitrification on their external surfaces suggesting that they may have protruded further into the furnace. The vitrification is mainly dark grey to black, of medium roughness usually with rounded features indicating that it was once molten. It is sometimes black and glassy on the nozzle extremity where the temperature was likely to have been higher and on a few examples there are some charcoal impressions. There are also some whitish-grey partially melted quartz crystals dotted within this vitrification. The vitrification on the fragments from 12/02/10 (3) (4) is slightly different being of a lighter grey, medium sandpaper roughness with few to no projections of material. On the better preserved examples (primarily from 06/02/10 (2) and 10/02/10 (1)) the vitrification is at an angle, going further up one side of the tuyere than the other suggesting that some would have been placed in the furnace wall at a slight angle with the nozzle facing down. However, their poor preservation does not allow the angle to be accurately measured.

The longest fragment from 10/02/10 (1) is slightly different as it has an additional clay lump placed on the upper side of the tuyere (orientation evident from the vitrified dribbles). This clay layer is up to 38mm thick and is present on the whole length of the surviving part of the tuyere. The outside layer is heavily vitrified and of medium porosity but the clay below is heavily reduced dark grey. This clay fabric is finer than the tuyere's, being of medium coarseness with some quartz inclusions. The tuyere was likely to have protruded at least 155mm inside the furnace. The fragment from 06/02/10 (2) also has some vitrified adhering clay. Beneath the vitrification is a thin layer of reduced clay suggesting that a thin layer may have been applied to the surface of the tuyere to help keep it in place or to protect it from the high temperatures. This clay is coarser in fabric than the tuyere's but similar to the furnace wall fragments found in the same location.

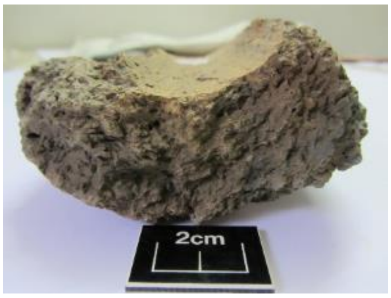
The only surviving rim fragment from 10/02/10 (1) is not vitrified and almost looks like it was not used. There is some additional clay on one side but it is not vitrified nor particularly reduced. It forms a layer approximately 18mm thick and breaks off around 20mm from the rim end. This means that the tuyere would not have been protruding much from the furnace wall. The top surface of this additional clay is flattened and uneven like the outside of the tuyere meaning that it was placed there purposely. It also tapers the furthest away from the rim end to become less than 5mm thick where the tuyere is broken. The clay seems quite coarse in comparison to the tuyere's with many small to medium sized quartz inclusions (most <3mm). Most of the tuyere and additional clay are oxidised orange in colour with some small areas of light grey. This suggests that it may not have been used and just fired in an oxidising blast. However, since the nozzle end has broken off, any evidence of use like vitrification may have been erased. It is not certain whether it is part of type 3 tuyeres as the walls appear thinner than most other examples but it has been categorised in this type due to the lack of rim flare and similar inner diameter.

06/02/10 (2)

10/02/10 (1)

10/02/10 (1)

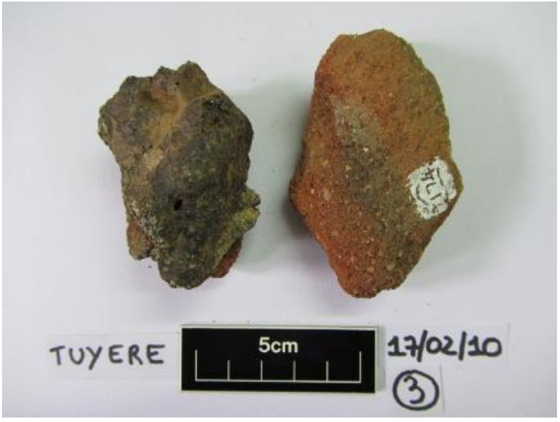
10/02/10 (1)



12/02/10 (3)

12/02/10 (4)

15/02/10 (4)



17/02/10 (3)

21/02/10 (3)

24/02/10 (3)


08/02/10 (1)


08/02/10 (4)

Appendix C.5.4 – T4

Characteristic features	Small inner diameters; very slight inner diameter taper to nozzle (almost tubular); very thin walls; long?
Fabric	Fine to low coarseness with very few quartz inclusions and possibility of organic temper
Size range	Incomplete length <70mm; 30-32 internal diameter at closest surviving part to rim; 25-28mm internal diameter at nozzle; 4-11mm wall thickness
Locations in which found	12/02/10 (1) (6)

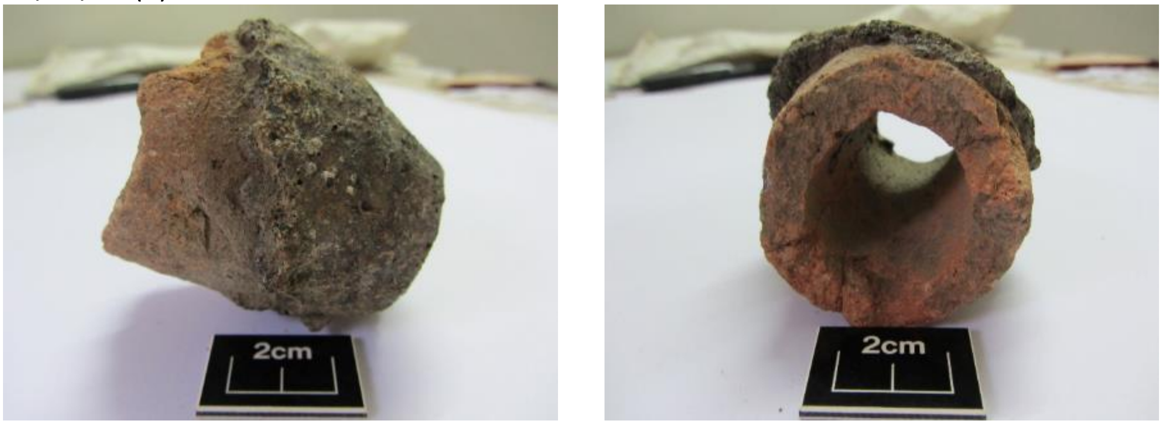
Type 4 tuyeres were only found in two locations: one nozzle end fragment with complete circumference from 12/02/10 (6) and two from 12/02/10 (1). In addition four more fragmentary pieces were found at 12/02/10 (1) as well as one almost complete tuyere which differs slightly. The main morphological characteristics which define tuyeres of this type are very thin walls and a small inner diameter with a very slight taper towards the nozzle end (almost tubular). The nozzle fragments with complete circumferences survive between 61-70mm in length but the rim ends are missing meaning that their original length cannot be estimated. Their inner diameters range from 30-32mm at the closest surviving part to the rim to 25-28mm at the nozzle end. The walls vary in thickness between 4-11mm. Their fabrics are fine to low coarse with few or no quartz crystals but maybe some organic inclusions. The fractures are worn and abraded making it hard to distinguish the fabric composition. All examples are built in the usual fashion which is moulded around a cylindrical object. Most have internal slip striations and external finger or moulding marks. The interior surface of some examples are remarkably smooth which suggests that some may have been moulded on a harder, smoother object. They range in colour from a pale orangey colour at the closest surviving ends to the rims changing to light and dark grey close to the nozzle ends. Two fragments from 12/02/10 (1); one nozzle piece and the largest fragment are fully dark grey reduced. All fragments also have some vitrification at the nozzle end.

This vitrification is similar on all examples. It is pale black in colour ranging from smooth to low sandpaper rough. There are no major protrusions of material and in some parts it is glassy black. There are also a few whitish-grey partially melted quartz crystals dotted in the vitrification. It is thin, usually between 3-7mm and on all examples appears to have broken off abruptly/cleanly further up the tuyere (where the vitrification is at its thickest perhaps due to the melting of the wall). It is likely that where the vitrification broke was the start of the wall structure. Of special interest is that the vitrification on all tuyeres seems to be at an angle going further up one side than the other. The vitrification on the fragment from 12/02/10 (6) goes up 30mm on one side and 50mm on the other while the fragments from 12/02/10 (1) have vitrification 20mm from the nozzle end on one side and 45-50mm on the other. This suggests that the tuyeres were placed at an approximate 30 degrees angle in the furnace or hearth structure. Although their orientation is hard to determine, the nozzle end of the tuyeres were likely facing down into the furnace or hearth. The tuyeres were also not protruding more than 50mm inside the structure.

One fragment from 12/02/10 (1) has adhering refractory wall which is oxidised dark red in colour. It seems to be of medium coarseness with quartz inclusions and some tiny slag inclusions. The clay lining is vitrified on the interior side with the usual dark grey to black medium rough vitrification with small rounded projections. The position of the tuyere in the remaining wall proves that they were placed at an angle with the nozzle facing down into the furnace or hearth. Of special interest is that it appears to have been positioned at a slight sideways angle perhaps indicating that more than one tuyere was placed into the furnace or hearth walls. The original exterior surface of the wall does not survive which limits further interpretation.

There is an almost complete tuyere fragment from 12/02/10 (1) made of the same fabric but differing slightly in size from all other fragments of this type. Its inner diameter is smaller and it appears to be a variation of the other type 4 tuyeres. It is 160mm in length but the rim end and extremity of the nozzle are missing meaning that it is likely to have been longer. The inner diameter at the nozzle end is 22mm and about 23mm at the furthest surviving end, towards the rim. Therefore, unlike the others, the inner diameter does not taper but the thickness of the walls do. The walls are 8mm thick at the rim end tapering to 3-4mm thick at the nozzle end. One side of the tuyere is reduced dark to light grey while the rest of it is light orange in colour. It seems that this tuyere was not used but may have been fired in a fire with the reduced side on or facing the heat source. If this fragment was used it may have had a different function or perhaps the vitrification has broken off.

12/02/10 (6)



12/02/10 (6)

12/02/10 (1)

12/02/10 (1)

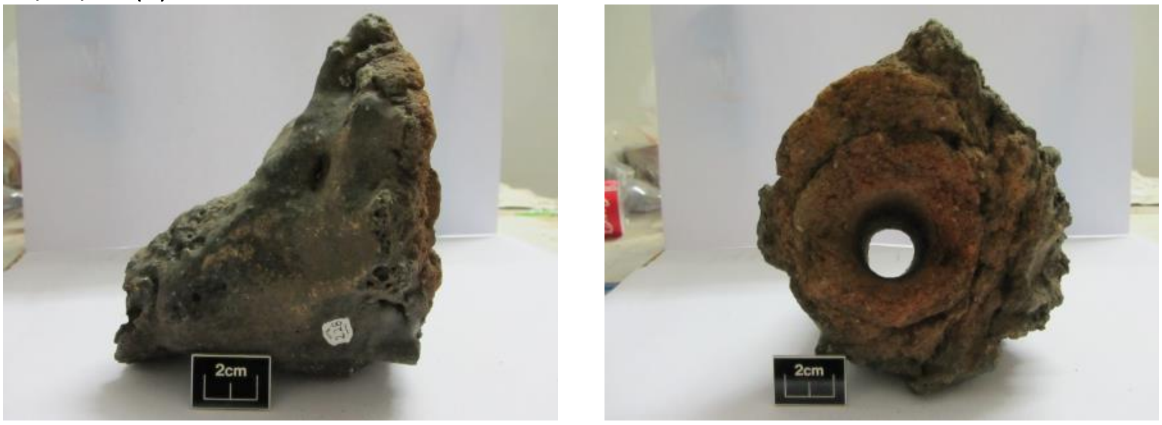
12/02/10 (1)

Appendix C.5.5 – TND1, 2, 3, 4

Several tuyere fragments are hard to categorise either because they are badly preserved, or because they have some morphological characteristics which could fit into more than one or none of the four tuyere types identified above. All tuyere fragments have inner slip striations and an uneven exterior surface suggesting that they were, like all other tuyeres, moulded around a cylindrical object. To facilitate discussion these have been divided into four main categories.

Category 1: The fragments from 23/02/10 (4), 25/02/10 (1) and 26/02/10 (5/6) are all reasonably well preserved with complete circumferences but the nozzle and rim ends are missing. They are made of a medium coarse clay fabric dominated by small quartz inclusions. Their inner diameters taper towards the nozzle end ranging from 30-35mm at the closest surviving part to the nozzle and 40-50mm at the closest surviving part to the rim end. The best preserved example survives to 167mm in length. These may be a variation of the long type 2 tuyeres but the walls are slightly thicker than the type 2 average and there is no sign of a flaring rim. The entire outside surface (130mm in length) of the fragment from 25/02/10 (1) is covered in a thick layer of vitrification and there are remains of non-vitrified wall at the rim end (up to 57mm thick). The vitrification is black and for the most part solid and smooth with well-rounded flow like features. In some areas there are sharper tiny protrusions and some dark reddish-brown patches which are magnetic (there may be some slag but uncertain). The shape of the vitrification suggests that the tuyere was placed in the furnace wall at an approximate 20 degree angle with the nozzle end facing down into the furnace. The vitrification on the fragments from 23/02/10 (4) and 26/02/10 (5/6) appears to have chipped off and the majority of the tuyeres are orangey oxidised, except near the nozzle end where they are dark grey reduced.

23/02/10 (4)



25/02/10 (1)

26/02/10 (5/6)

Category 2: Several non-diagnostic, very fragmentary tuyere rim fragments were recovered; two from 29/01/10 (1) and one from both 26/02/10 (1) and (8). The two from 26/02/10 (1) (8) are almost identical with a similar low to medium coarse fabric and the same medium to dark grey reduced colour. They are both between 13-15mm thick. The larger one from 29/01/10 (1) is slightly thicker at 20mm and is mainly orangey oxidised with a coarse fabric. The curvatures on all fragments point to an internal diameter at the rim of around 60-70mm and none show any signs of flaring. The rim ends are flattened with the edges slightly rounded. Due to their small size and their lack of a distinct flare, these fragments are non-diagnostic.

29/01/10 (1)

26/02/10 (1)

26/02/10 (8)

Category 3: Several unique tuyere fragments were recovered from 02/02/10 (8), of which two have a complete circumference surviving intact up to 60mm from the nozzle end. The tuyeres are vitrified at the nozzle with a molten and rough appearance. However, this vitrification seems to end abruptly a few centimetres from the end (30mm maximum). This means that the tuyeres did not protrude much inside the furnace unless a significant proportion of tuyere melted inside the structure. The walls are more reduced on the outside ranging from dark to light grey and then dark brownish-red in the inside. The fabric is very coarse dominated by small quartz or stone inclusions (mainly <2mm). The walls are reasonably thick, varying in size from 15-17mm while their inner diameter at the nozzle end ranges from 20-30mm. They appear to be tubular in shape with no or very little taper towards the nozzle (hard to tell as not much tuyere length survives). Like all tuyeres they seem to have been moulded around a cylindrical object as the interior surface is smooth with slip striations while the outside seems to have been moulded by hand with subtle uneven bumps. Due to their poor preservation, their original length and shape cannot be determined.

02/02/10 (8)

02/02/10 (8)

Category 4: Of special interest are some of the non-diagnostic fragments from 09/02/10 (2) and 22/02/10 (1). Their fabrics differ slightly by being of low coarseness with few quartz crystals <1mm in size. They may also contain some organic material but it is hard to ascertain. Their exterior surfaces have thin vitrification which seems to be primarily greyish-white in colour and rough to the touch. It is possible that these tuyeres were covered with an exterior layer of quartz rich clay.



22/02/10 (1)



09/02/10 (2)

Non-diagnostic: Several very fragmentary tuyere pieces were recovered from locations 03/02/10 (15), 08/02/10 (5), 09/02/10 (2), 19/02/10 (3) (6), 21/02/10 (7), 22/02/10 (1) (3), 23/02/10 (1) (4) (5) (6), 25/02/10 (3), 26/02/10 (7). These are all very small fragments without complete circumferences and rim/nozzle ends making it impossible to positively attribute them to any of the four main types discussed above. Their fabric and wall thickness suggests that they are more likely to have come from type 1 or type 2 tuyeres.



08/02/10 (5)

22/02/10 (3)

23/02/10 (1)

26/02/10 (7)

Appendix C.6 – Crucibles

Crucible steel production sites were identified during the 2010 Pioneering Metallurgy Project and many crucible fragments were collected. Two main crucible types were identified, with the possibility of a third type combining morphological features of the two main types. This section will be the general descriptions of these main crucible types. Table 1 below gives the weight of the material found in each location categorised by type. All photographs relate to the text directly preceding them.

Table 1 - Weight in grams of crucible material collected in each location categorised by type.

Location	**Type C1** (total g)	**Type C2** (total g)	**Type C3** (total g)	**Non-diagnostic** (total g)
26/01/10 (8)	-	-	-	448
29/01/10 (1)	-	2270	-	-
29/01/10 (2)	-	-	-	60
29/01/10 (4)	-	546	-	-
06/02/10 (2)	-	550	-	-
08/02/10 (9)	-	2117	-	-
08/02/10 (10)	-	15	-	-
09/02/10 (1)	6728	-	-	-
09/02/10 (2)	9195	-	-	-
09/02/10 (5)	3914	-	-	-
10/02/10 (1)	3420	-	-	-
10/02/10 (2)	1934	-	-	-
10/02/10 (3)	29 non-dia	-	-	-
10/02/10 (4)	2743	-	-	-
12/02/10 (1)	-	-	376	-
12/02/10 (2)	-	-	576	-
12/02/10 (3)	-	-	2788	-
12/02/10 (4)	-	-	1065 (+geoblock)	-
12/02/10 (5)	-	-	904	-
16/02/10 (4)	-	-	-	158
17/02/10 (1)	-	-	-	156
17/02/10 (2)	-	2350	-	-
17/02/10 (3)	-	363	-	-
17/02/10 (4)	-	-	-	10
18/02/10 (1)	-	-	-	210
21/02/10 (1)	-	-	146	-
21/02/10 (2)	-	-	-	50
21/02/10 (3)	-	-	3110	-

Location	Type C1 (total g)	Type C2 (total g)	Type C3 (total g)	Non-diagnostic (total g)
21/02/10 (5)	-	-	-	30
21/02/10 (6)	-	-	-	100
21/02/10 (7)	-	-	1645	-
21/02/10 (8)	-	-	575	-
22/02/10 (1)	7789	-	-	-
25/02/10 (1)	-	497	-	-
26/02/10 (5)	-	201	-	-
26/02/10 (6)	-	1344	-	-
27/02/10 (5)	-	80	-	-
Total				

Appendix C.6.1 – C1

Characteristic features	Large size range; flat base; conical lid
Size range	Internal chamber 25-119mm diameter and 25-63mm height; external height 75-120mm; wall thickness 5-25mm
Probable steel ingot size range	12-32 x 25-119mm
Locations in which found	09/02/10 (1) (2) (5); 10/02/10 (1) (2) (3) (4); 22/02/10 (1)

The major characteristics of this crucible type are the large size range and the predominant morphological features of a flat base and conical lid. The crucibles in this type ranged in size from 25-119mm in internal chamber diameter, 25-63mm in internal chamber height, 75-120mm in external height and 5-25mm in wall thickness. From these measurements it is possible to estimate the size of the resulting crucible steel ingots to 12-40mm in height and 25-119mm in diameter. The crucibles seem to have been built in three broad sizes.

- Small: 25-37mm internal chamber diameter, 25-35mm internal chamber height, 75-87mm external height and 5-12mm wall thickness. Producing an ingot size of around 12-15mm in height and 25-37mm in diameter.
- Medium: 40-60mm internal chamber diameter, 30-35mm internal chamber height, 95-100mm external height and 9-14mm wall thickness. Producing an ingot size of around 15-20mm in height and 40-60mm in diameter.
- Large: 78-119mm internal chamber diameter, 40-63mm internal chamber height, 100-120mm external height and 6-25mm wall thickness. Producing an ingot size of around 20-40mm in height and 78-119mm in diameter.

No crucible survived whole, the majority being fragmentary with bases and lids being the best preserved with some more fragmentary body fragments. In some cases there are significant proportions of the crucible body surviving attached to either base or lid which enable the crucibles to be more accurately measured. All crucible fragments of this type are made of a similar reduced, fine, black fabric with some voids indicating that an organic component was present. These voids are either small (<1mm) and spherical or slightly elongated up to 4mm in length. Correlating this to previous microstructural examinations of this crucible fabric type it suggests that either rice or millet husks formed part of the ceramic matrix. This ceramic fabric which makes up the crucible walls varied in thickness depending on the size of the crucible but also varies on individual crucibles. It was noticed that the thickness of the bodies on the smaller examples was greater than their bases and that it tapered slightly towards the crucible rim. On the larger examples the body was thinner than the bases and it also tapered towards the rim. The shape of the crucibles also vary slightly depending on the size. The small and medium-sized crucibles have flat bases on the interior but the exterior has a slight curvature to it. Their lids are conical in shape sometimes quite pointed like pine cones. The large sized crucibles have flat bases on the interior and exterior as well as conical lids, usually less pointed than the smaller examples. These conical lids make up a significant proportion of the whole crucible; on average about half of the crucible height.

Of special interest are that the majority of the lids have two angular impressions on either side of the cone shape suggesting that they had been moved with tongs. It is uncertain whether these impressions were made when the crucibles were placed in the furnace (when the lid clay may have been unfired) or when the crucibles were moved or removed during/after firing (if the clay was molten and malleable). Although the majority of the lid fragments do not show any signs of perforations, a few of them do have one central perforation. Three out of the five lid fragments from 10/02/10 (2) have a central hole about 3mm in diameter and in one example it clearly goes all the way through the lid. Two of these also have an external impression around the perforation, 12-13mm in diameter and about 10-15mm deep as if a stick had been thinned out on one end or as if a finger had made an impression where the hole would be. A fragment without a perforation in the same location has an additional lump of clay protruding from the crucible lid centre where a hole might be expected. It is possible that the perforations were covered during firing. The lids with perforations seem to have some dark brownish red patches on the outside surface (which may be corrosion) meaning that some of the molten metal may have escaped. A perforation about 5mm in diameter was also noticed on the underside of a lid fragment from 22/02/10 (1) but it does not appear to go through to the outer surface.

The exterior of the crucibles is dominated by heavy vitrification. This vitrification varies in colour from dull dark grey to glassy black and glassy translucent dark green. It is also often dotted with whitish-grey partially melted quartz crystals which dominates on some examples. The texture is usually of a low roughness (medium grade sandpaper rough) with well-rounded smoother features and very little projections of material. Of special interest is that this vitrification is predominant on the top half or top ⅔ of the crucibles with the lower parts and bases having a finer dark grey to black glassy vitrification. It is clear from the body sherd sections that the outer parts of the crucible were coated with a quartz-rich clay which thinned out the further down the crucible it went. This clay appears to be the same as the crucible lids (a lid fragment from 09/02/10 (1) which is not fully vitrified shows that the vitrified surface on the exterior is the same fabric as the clay used for the lids) suggesting that the crucibles were sealed with a coarser quartz-rich clay which was also smeared on the outside of the crucible. This may explain why the wall thickness of the crucibles taper at the rim so that when the exterior clay coating is applied, the exterior is uniform and smooth. Whether this was intentionally done to make the crucibles more aesthetic or to limit protruding clay material impeding stacking and their placement in furnace is not possible to determine. It may also have been a more effective way of locking together crucible and lid to form a durable join and making them more resistant to high temperatures. The bases of the crucibles are for the most part free of this coarser clay coating but the crucible wall is also vitrified forming a dull dark grey to black glassy layer on the surface. This glassy layer has rounded, molten features and on the larger examples there are large charcoal impressions (up to 40mm) sometimes with some small stone and quartz inclusions. The melting of the walls is clear as the rounded flows of vitrification seem to have flowed down the crucibles sometimes forming a thicker layer on the bases giving some of the larger base fragments a more rounded exterior appearance.

All the interiors of the crucibles are similar accept the size of the inner chambers. The majority of the body fragments have a black glassy fin adhering to the side wall. This fin represents the upper limit of the formed crucible steel ingot where a black glassy slag layer formed and solidified above it. The melted steel being denser sunk to the bottom of the crucible while all the less dense slaggy impurities floated above it. When the crucibles cooled, the metal ingot and the glassy slag solidified and could easily be separated. For this reason no complete glassy slag layer survives; only the glassy fins attached to the side of the walls remain. These fins are usually triangular in profile with the thickest parts adhering to the crucible wall and they are broken where they would have extended across the top of the ingot. This is undoubtedly due to the greater surface tension against the wall which allowed more glassy material to remain there. The underside of these fins tends to be dominated by gas voids (porous) while the top surfaces are generally smooth. The inside of the crucibles below this fin are for the most part lined with a very thin coating of porous (very small spherical gas voids) black glassy slag once again probably due to the greater surface tension against the walls. Above this fin, the crucible walls are usually lined with dark brownish red rusty patches and sometimes a few metallic prills (up to 3mm) which are magnetic. These are also common on the underside of the lids meaning that the iron in its molten state reacted with the carbon and boiled (carbon boil). In a few cases the wall above the fins have a thin, smooth black glassy slag lining which is indicative that they were moved when the charge was still molten and the glassy slag agitated, lining the upper parts of the crucibles. In most examples the glassy fins are horizontal (same plane as the base) but in a few cases, especially in the smaller crucibles (09/02/10 (1) (2) (5)) these are slanted sometimes even reaching the lid meaning that the crucibles may have moved or been dislodged while in the furnace or after removal. In one specific example (09/02/10 (1)) there is a fragment with a horizontal glassy slag fin which breaks half way to become almost a vertical rim meaning that at some point while the metal was still liquid the crucible was put on its side. Whether or not this was intentional is not known but since the majority of the crucible fragments found have a horizontal fin it is safe to suggest that it was accidental. Since the glassy slag fins represent the upper limit of the steel ingots, their rough size and volume can be determined. In most cases the ingot seems to occupy approximately half to ⅔ of the inner chamber volume of the smaller crucibles and as little as ⅓ of the larger crucibles (09/02/10 (1) (2)). The majority of the crucible internal surfaces are free of any impressions but in both the small and medium sized crucibles from 09/02/10 (1) (2) there seems to be very small charcoal impressions or inclusions on the underside of the lids (<5mm). This suggests that charcoal or wood may have been one of the ingredients put into these crucibles.

There is also evidence for crucible stacking in the furnaces. Some of the small and medium fragments are fused to other fragments. A fragment from 09/02/10 (1) has three fused crucible pieces of which two are at the same level with the third placed above (base fragment attached to the two lids) suggesting that the crucibles were stacked in the furnace. Two medium-sized crucible fragments were also fused (two body sherds stuck together) in the same location and these seem to have more rounded lids with no tong-marks but it seems likely that due to the stacking the lids were partially compressed. Another fused piece with two small crucibles was found from 10/02/10 (1) and a lump of fused crucibles was recovered from 22/02/10 (1). All fused crucibles were placed upright in the furnace but they appear to have moved slightly during firing. The large crucibles show no evidence of stacking. They may have been put into the furnace individually and since their bases are flat with large charcoal inclusions it is likely that they would have rested on the bottom of the furnace unlike the smaller examples that have slightly curved undersides and were likely held in the charcoal charge. All fused crucibles seem to be of a similar size suggesting that crucibles were fired together in batches of the same size. It is important to note that some of the fused crucibles (especially the lump from 22/02/10 (1)) have unusual external vitrification in between. The usual vitrification is present but there are also large patches of dull light grey to pale yellow which have a medium sandpaper (gritty) texture. It may have been produced by the external lining of the crucibles but it resembles more the light grey geological material (limestone/sandstone) which is connected to the green glassy slag material common on crucible sites (discussed in coloured glassy slag section). Some sort of material may have been added to the furnace in addition to the crucibles; perhaps additional quartz rich clay or lime/sandstone to help keep the crucibles in place or protect them from the high temperatures.

Two fragments also show signs of failure. A crucible fragment from 09/02/10 (5) has a collapsed lid which partially melted into the crucible chamber and shows signs of having been in contact with the molten charge as there is a significant amount of black glassy slag residue on it. The lump of fused crucibles from 22/02/10 (1) contains many broken fragments which seem to have lost their charge. The ceramic fabric of some of these crucibles are also of a different colour, being dark brownish-purplish-red. This is undoubtedly a result of them breaking during firing as they may have been removed before they had a chance of reducing totally. Another possibility is that the black fabric colour is due to the melting of the charge which may not have happened before they broke.

09/02/10 (1)

09/02/10 (1)

09/02/10 (1)

09/02/10 (1)

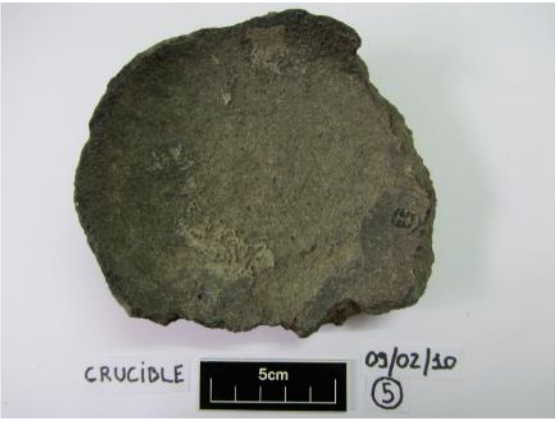
09/02/10 (2)

09/02/10 (1)

09/02/10 (1)


09/02/10 (1)

09/02/10 (2)



09/02/10 (5)

09/02/10 (5)

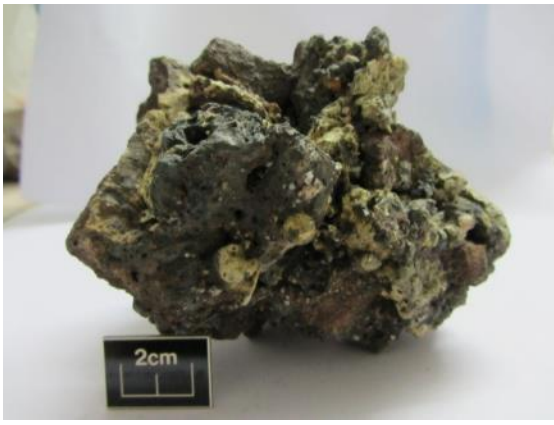
10/02/10 (1)

10/02/10 (1)

10/02/10 (2)

10/02/10 (2)

10/02/10 (4)



22/02/10 (1)

09/02/10 (5)

Appendix C.6.1.1 – Unused C1 crucibles

Two unused crucible body fragments were also recovered. One large fragment from 09/02/10 (5) and one smaller fragment from 10/02/10 (1). The fragment from 09/02/10 (5) appears to be a ¼ section of a large crucible (convex exterior shaped like a meditation bowl) with an inner chamber of around 120-140mm in diameter and 60mm in height with a body height (without lid) of 80mm. The wall thickness varies between 16-23mm, being thinner at the rim, and it seems to have had a flat base like those seen in the used examples. The fragment from 10/02/10 (1) is almost a perfect half section through a small crucible (40mm tall without lid) with an inner chamber 40mm in diameter and 25mm in height. The wall thickness is thickest at the base (14mm) which is flat on the inside but curved on the exterior and thins out closer to the rim to a few millimetres.

Both fragments have a similar fine, almost fibre like fabric with many very small white organic inclusions which may be crushed cereal grains (maybe rice or millet husks). Both also appear to have been unused as their fabrics are mainly of a pale to dark orange colour but there is a vitrified exterior on the fragment from 10/02/10 (1) suggesting that it was placed in the furnace and perhaps broke during the process while the other goes to a dark grey closer to the interior surface suggesting that it may have been fired. Both appear to have been moulded or at least finished by hand as they have large horizontal finger striations on their exterior surfaces while the insides appear to have been smoothed by hand with vertical smooth lines on the larger fragment and horizontal ones in the smaller fragment. The smaller fragment has a small central lump at the base which looks like a finger smoothed the inner part of the crucible leaving some clay material in the centre of the base (the index finger fits well against the inner wall). As the smaller fragment has almost the same inner diameter as other fragments from the same location it is possible that a mould was used to shape the crucibles prior to being finished by hand. Of special interest is the surviving exterior vitrified surface on the smaller fragment. It shows clearly that a separate exterior layer of coarser quartz rich clay was applied (most likely when the lid was fixed). This layer has chipped off on one part showing that as the thickness of the crucible wall gets thinner towards the rim the coarser layer gets thicker making the crucible almost even in thickness all the way up the body with almost no coarser clay at the base giving the crucible an even rounded appearance.

09/02/10 (5)

09/02/10 (5)

10/02/10 (1)

10/02/10 (1)

Appendix C.6.2 – C2

Characteristic features	Small size range; domed base; domed lid
Size range	Internal chamber 30-55mm diameter and 30-50mm height; external height 55-90mm; wall thickness 3-17mm
Probable steel ingot size range	17-40 x 30-55mm
Locations in which found	29/01/10 (1) (4); 06/02/10 (2); 08/02/10 (9) (10); 17/02/10 (2) (3); 25/02/10 (1); 26/02/10 (5) (6); 27/02/10 (5)

The major characteristics of this crucible type are their small size and the predominant morphological features of a rounded base and domed lid. The crucibles in this type ranged in size from 30-55mm in internal chamber diameter, 30-50mm in internal chamber height, 55-90mm in external height and 3-17mm in wall thickness (most around 8-15mm). From these measurements it is possible to estimate the size of the resulting crucible steel ingots to 17-40mm in height and 30-55mm in diameter.

All crucibles recovered were broken and fragmentary; the bases survived better as they tended to be thicker but in many locations substantial body and lid fragments were also recovered. In a few cases almost half sections of crucibles also survived enabling more accurate measurements to be taken. They are all made of the same or similar fine black fabric with a significant organic component. The small voids present in the ceramic fabric would point to cereal grains. Crucibles of this type all have rounded or domed exterior bases (almost semi-circular in profile) and, unlike the small type 1 crucibles, the interior also seem to be curved. In a few cases (notably from 29/01/10 (1), one from 06/02/10 (2) and some from 26/02/10 (6)) the exterior bases of some crucibles appear almost pointed or conical but this may be due to the melting of the external wall or coating which may have dripped down to reshape/distort the base. The wall thicknesses are for the most part quite thin (<8mm) with the base being generally thicker (up to 17mm) and the wall thinning towards the rim.

They also all have domed lids which are generally quite low in height compared to the type 3 crucibles lids. The lids only contribute about ¼ to a ⅓ of the crucible height. It may also be significant that no lids or crucible body fragments have tong marks as seen in the type 1 crucibles. Two lid fragments from 17/02/10 (2) appear to have small perforations or intentionally made depressions in their centres. The holes are conical shaped with a wider diameter at the top (<15mm) tapering as it goes into the lids (<8mm). It almost appears as if a long thin object was pushed into the lids and swirled around. They also appear to be surrounded by a small rounded lip on the exterior made of the same material as the external lining (quartz rich clay). This may have been an intentional addition of material but it cannot be ascertained as it could have been material pushed to the sides when the holes were made. It is also worth noting that the exterior depressions in the lids do not appear to go straight through it as no visible holes are present on the inside of the lids. No other perforations were observed any other lids but a few fragments from 08/02/10 (9) (10) did have a small rounded vitrified knob or lump in the centre of their external surfaces. This additional clay (of the same composition as the lids) may have been added to plug holes but since they no longer have any external evidence of these it cannot be certified.

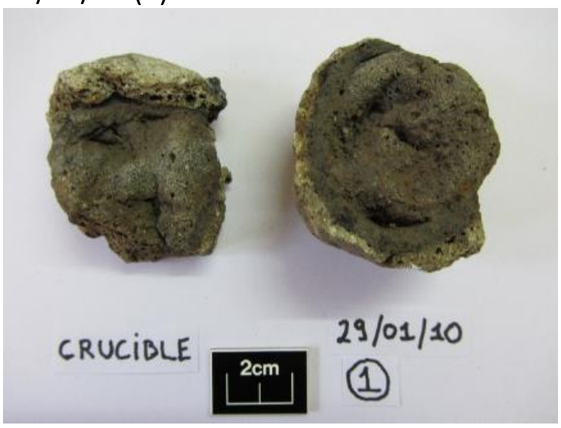
The exterior surfaces of the crucible fragments in this type are very similar to the ones in type 1. Their exterior surfaces are dominated by heavy vitrification of medium sandpaper coarseness. This vitrification is mainly of a dark grey to black colour dominated by either large dull greyish-white patches or greyish-white speckles which must be partially melted quartz crystals. In some examples there are also small glassy patches of pale to dark green or blue. This coarser material (primarily consisting of quartz crystals mostly <1mm) appears to be the same fabric as the crucible lids which was smeared on a good proportion of the exterior crucible walls. On a few crucible fragments (in 06-02-10 (2), 17/02/10 (2) (3) and 25/02/10 (1)) this exterior coating seems to have partially detached from the main crucible ceramic fabric leaving elongated voids between the two layers. This adds additional support to the idea that this material was indeed a separate coarser clay layer. Similar to the type 1 crucibles, this external coating did not cover the whole crucible but approximately ⅔ to ¾ leaving the black crucible fabric exposed at the base. The coating was up to 11mm thick at the top of the crucibles (usually less) reducing in thickness towards the base leaving the exterior evenly rounded. The bases of the crucible fragments were mainly covered by black glassy vitrification with some charcoal impressions of varying sizes (mainly <15mm). Due to their rounded base profiles the crucibles must have been supported by the charcoal charge and not placed on the bottom of the furnace.

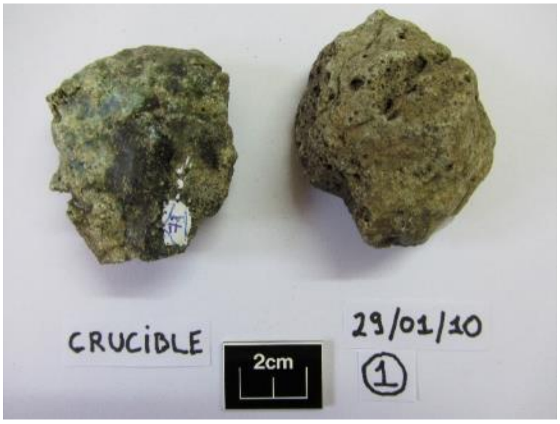
Their internal features are also similar to other crucible types. The main feature is the black glassy slag which usually forms a horizontal fin on the side wall of the crucibles. These tend to be less well preserved in most cases than the fins in the type 1 crucibles and sometimes only thin, faint glassy lines remain. In some examples these fins are not perfectly horizontal, adhering at a slight angle suggesting that the crucibles may have moved during firing. This glassy fin indicates the size of the resulting steel ingots and in the majority recorded these filled approximately ⅔ of the inner crucible chamber. The exception are a few fragments from 29/01/10 (1) which appear to have filled most of the chamber and the fragments from 26/02/10 (6) which only appear to fill half of the inner crucible chamber. The crucible walls below the glassy fin are usually lined with a thin coating of the same porous (dominated by small spherical gas voids) black glassy slag. Above the fin, the walls are either bare but most often have a dark brownish orangey-red coating which must be corroded iron-rich regions. On the better preserved lid fragments small (<2mm) spherical metallic prills (with the same dark brownish-red coating) can be seen adhering to their undersides suggesting that the molten metal carbon boiled. The underside of these lids are less vitrified than the exterior surfaces and very fine quartz crystals (mostly <1mm) can be seen dominating their matrix. All of the crucible fragments have slightly asymmetrical interior surfaces and although this may have been partially caused by the distortion of the ceramic body at high temperatures it suggests that these crucibles were moulded or at least finished by hand. The fragments from 26/02/10 (5) (6) have faint horizontal smooth lines (like concentric circles) on the internal walls and some have a small central raised lump at the base like seen in the small unused type 1 crucible. This shows that the index finger fits well against the internal walls adding credence to this hypothesis.

Some crucible fragments are fused together (in 29/01/10 (1) (4), 06-02-10 (2), 08-02-10 (9), 17-02-10 (2) (3), 25-02-10 (1) and 26/02/10 (6)) suggesting that more than one crucible was placed into the furnace at a time which is not surprising due to their small size. The majority of these comprise of one body fragment fused to another but in 17/02/10 (2) three body fragments are fused together. These are generally fused in the same vertical orientation with some that appear to have moved slightly during firing. For the most part there is no evidence that these crucibles were stacked on top of each other except in 17/02/10 (2) where a piece with two fused body fragments also has a third base fragment fused to the top of their lids and another example with a base fragment fused to a lid fragment. It is also important to note that many of these small crucible fragments appear to have been deformed, probably due to their thin walls being less resistant to high temperatures. Some of this sagging may also have been caused by the weight of other crucibles around them, either placed next to each other or stacked.

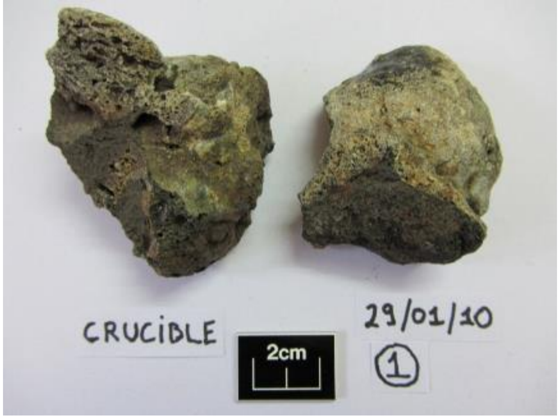
29/01/10 (1)

29/01/10 (1)



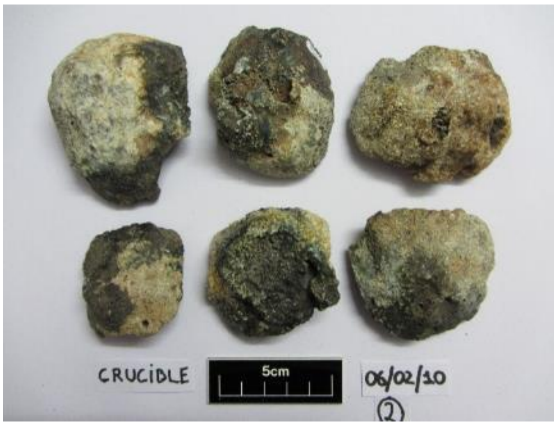


29/01/10 (1)



29/01/10 (1)

06/02/10 (2)



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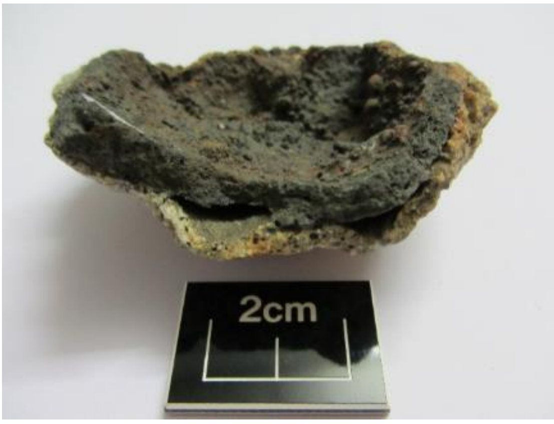
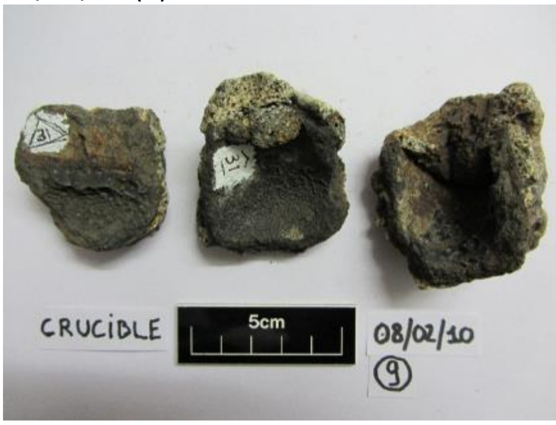
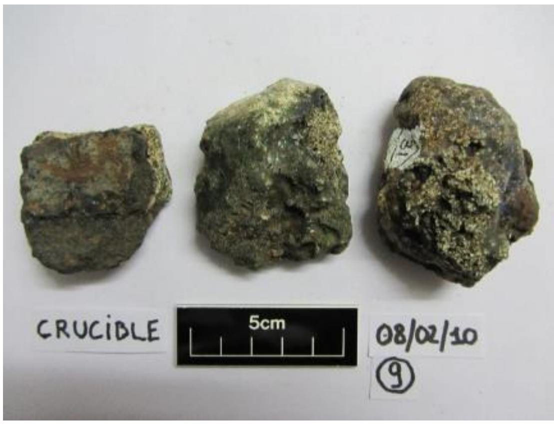


06/02/10 (2)

08/02/10 (9)



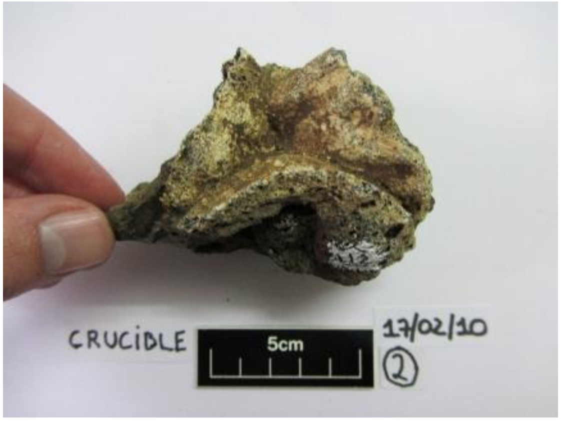


08/02/10 (9)

08/02/10 (9)

08/02/10 (9)


17/02/10 (2)



17/02/10 (2)

17/02/10 (3)

25/02/10 (1)

25/02/10 (1)

25/02/10 (1)

26/02/10 (6)

26/02/10 (6)

26/02/10 (6)

Appendix C.6.3 – C3

Characteristic features	Large size range; flat or slightly domed base; domed lid
Size range	Internal chamber 48-103mm diameter and 50-55mm height; external height 65->75mm; wall thickness 5-25mm
Probable steel ingot size range	10-35 x 48-103mm
Locations in which found	12/02/10 (1) (2) (3) (4) (5); 21/02/10 (1) (3) (7) (8)

This material type is primarily based on the crucible remains found in locations 12/02/10 (1) (2) (3) (4) (5) and 21/02/10 (3) (7) which differ slightly from types 1 and 2. No crucibles survived complete but large base, body and lid fragments remain giving a good representation of their shape and size. They share many of the morphological characteristics described for the two other types but differ in that they have flat bases and domed lids. There are a greater number of small to medium sized crucibles which range in size from 48-80mm in internal chamber diameter, 50-55mm in internal chamber height, 65->75mm in external height and 5-13mm in wall thickness. The estimated size of the resulting crucible steel ingots is 10-25mm in height and 48-80mm in diameter. However, there is a lid fragment from 12/02/10 (4) which appears to have had an inner diameter of 93mm and a base fragment from 12/02/10 (5) with an inner diameter of 103mm. The wall thicknesses of these two fragments vary between 11-13mm. Unfortunately not enough of these large sized crucible fragments were recovered to estimate their full sizes. Several nice base fragments and domed lids where found in location 21/02/10 (3) suggesting an inner diameter between 75-102mm and wall thicknesses up to 23mm. The body fragments from 21/02/10 (7) also appear to have come from large crucibles with a wall thickness up to 25mm and an internal glassy fin height of up to 35mm. Their external height cannot be accurately estimated but some may have been in excess of 90mm. In addition to these there are also a few poorly preserved fragments from 21/02/10 (1) (8) which display similar characteristics. A few flat bases, domed lids and some body fragments were recovered indicating that their inner diameters were up to 95mm and wall thicknesses between 11-16mm. Their poor preservation means that their sizes cannot be fully measured but they seem similar to the larger crucibles from 12/02/10 and 21/02/10 (3) (7).

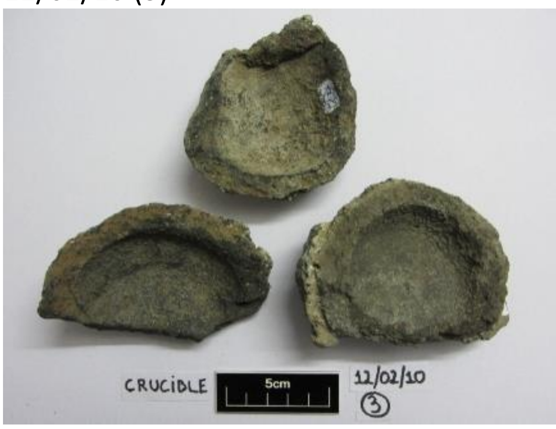
All the fragments appear to have flat bases but some of the smaller fragments may have had a slightly curved exterior. The lids are domed and do not have tong-marks unlike the conical examples of type 1. No lid fragments show any signs of having had perforations except the one from 21/02/10 (8). This broken fragment is approximately half of the original lid and in its section (centre of the original lid) there appears to have been a perforation which would have penetrated all the way through but is now partially fused. What is left is a small diameter (3mm) vertical gash where one might expect the hole to have been. The majority of the crucible walls are thicker at the base and the walls appear to thin towards to the rim although it is hard to tell because no rims survive.

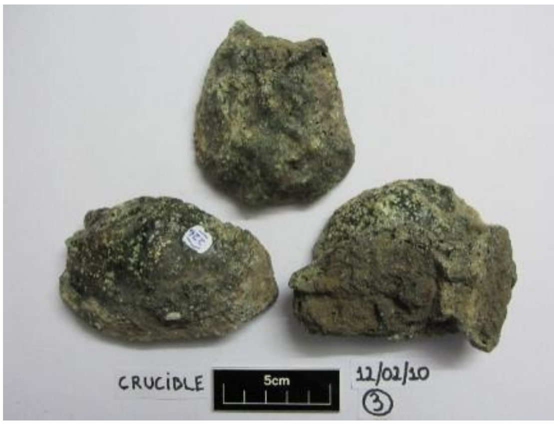
All the crucibles have the same fine black ceramic fabric with small voids suggesting that they were rich in organic material; probably cereal grains. The lids are made of a coarse quartz-rich clay which seems to have been thinly coated on the outside walls of the crucibles. The heavy external vitrification on the crucibles from 21/02/10 is mainly black to dark glassy-green, dominated by partially melted greyish-white quartz crystals. The vitrification on the crucibles from 12/02/10 on the other hand is almost fully dull greyish-white with some areas of glassy green and blue vitrification. Indeed on some of the fragments, especially the largest base fragment from 12/02/10 (5), there appears to be remains of this dull whitish-grey limestone or sandstone-like material which seems to turn into green glass when fully vitrified (discussed in geological section). Its composition or origin is not known but this material was likely put into the furnaces. As observed with all other crucible types, the external coarse clay vitrification is only present on the top ⅔ of the crucibles with the bases showing the black glassy vitrification of the crucible wall ceramic. There are also charcoal impressions on some of the bases.

The interior wall surfaces have the characteristic horizontal black glassy slag fin. This fin is usually well preserved and triangular in profile like the type 1 crucibles. The fins tend to be dominated by small spherical gas voids (porous) on their undersides while their top surfaces are solid, flat and smooth. They are wider against the walls and are broken where they would have extended across the top of the ingot. Below this fin the crucible walls are lined with a thin porous (very small spherical gas voids) layer of the same black glassy slag while above it the walls either have a thin coating of smooth glassy slag or, more commonly, a thin sandpaper-rough dark brownish orangey-red iron-rich coating. In some cases there are also very small metal prills on the underside of the lids. The position of the glassy fin in the crucibles from 12/02/10 show that the ingot only took up ¼ to ½ of the inner chamber space. This is significantly less than in type 1 and 2 crucibles, perhaps suggesting that different raw materials were charged. It is not possible to judge the ingot sizes of the 21/02/10 crucibles due to their poor preservation.

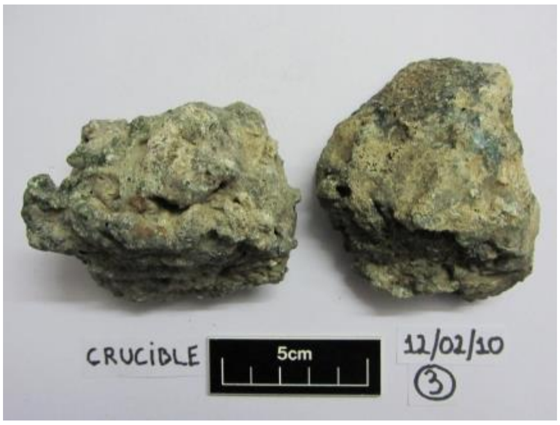
Some of the small to medium-sized crucibles from 12/02/10 (3) are fused with two or more body fragments fused together and there is one piece with a base fragment fused to a lid fragment. These are all in the same approximate upright orientation with some that may have moved slightly during firing. This suggests that more than one of the smaller crucibles would have been put into the furnaces and that they could also be stacked. The larger fragments with their flatter bases were more likely to have rested on the bottom of the furnace with no evidence of multiple examples in the same furnace.

12/02/10 (3)

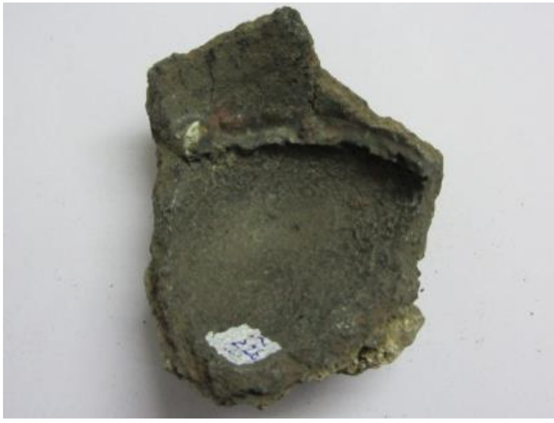




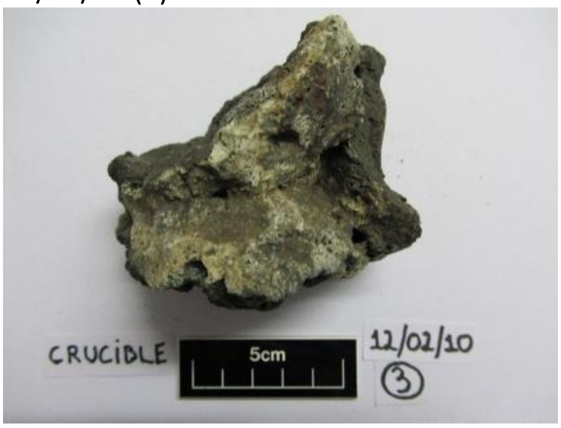
12/02/10 (3)



12/02/10 (3)

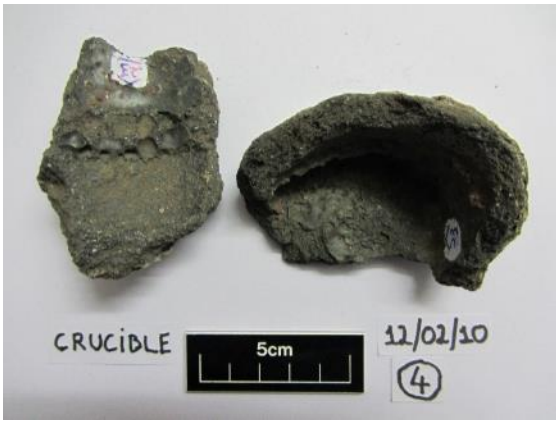


12/02/10 (3)



12/02/10 (3)

12/02/10 (3)

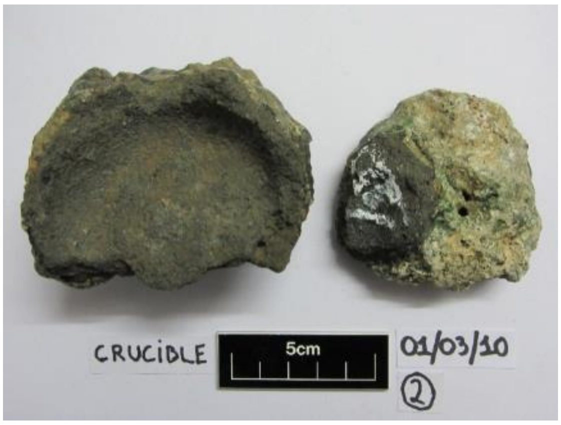


12/02/10 (4)

12/02/10 (4)

12/02/10 (4)

12/02/10 (5)



12/02/10 (2)

12/02/10 (2)

21/02/10 (1)

21/02/10 (3)


21/02/10 (3)

21/02/10 (8)

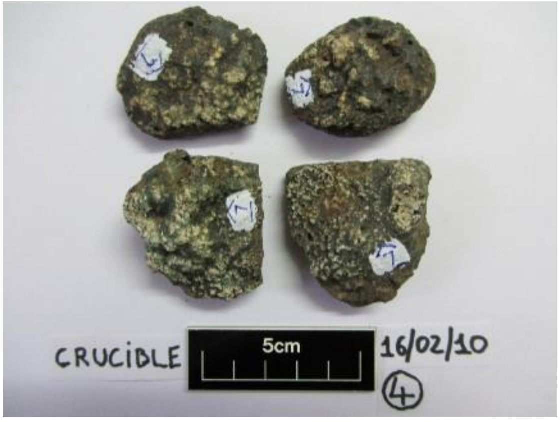
21/02/10 (8)

Appendix C.6.4 - CND

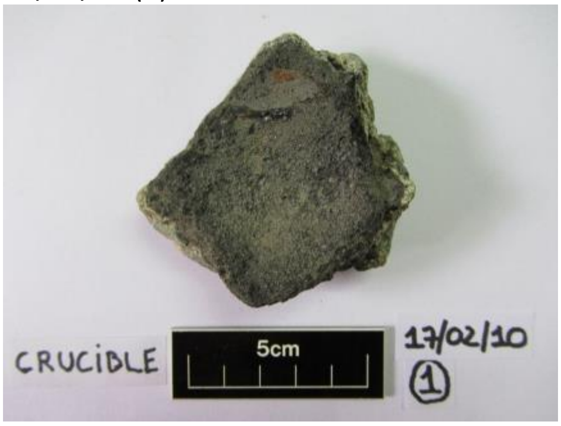
Characteristic features	Non-diagnostic
Size range	?
Probable steel ingot size range	?
Locations in which found	26/01/10 (8); 29/01/10 (2); 16/02/10 (4); 17/02/10 (1) (4); 18/02/10 (1); 21/02/10 (2) (5) (6)

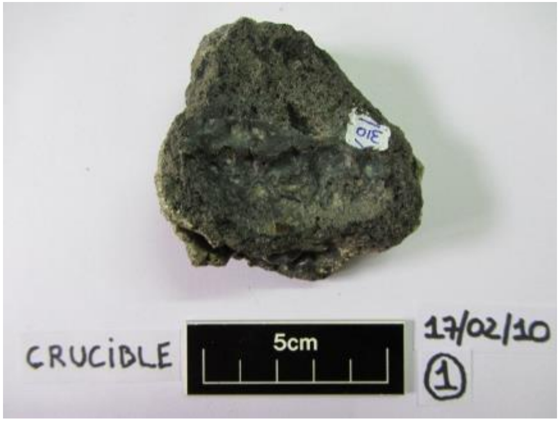
The crucible fragments from 26/01/10 (8), 29/01/10 (2), 16/02/10 (4), 17/02/10 (1) (4), 18/02/10 (1) and 21/02/10 (2) (5) (6) display the usual crucible characteristics as they are made of the same fine black organic-rich fabric, have heavy vitrification on the exterior surfaces and the black glassy fin is present on the interior surface of the body fragments. However, all the fragments are very small (mostly <60mm in size) with no surviving (intact) lids or bases so they cannot be positively attributed to one of the types above. Nevertheless, the thickness of the walls and general shape/size of the fragments give an indication of what type they may belong to. The fragments from 26/01/10 (8) are thin-walled and one appears to be a rounded lid. They also appear to come from very small crucibles suggesting that they probably were of type 2. One fragment from 17/02/10 (1) is made of two body sherds fused together and their thin walls as well as their general shape suggests that they were type 2 crucibles. The small fragments recovered from 21/02/10 (2), 17/02/10 (4), 16/02/10 (4) and 18/02/10 (1) are also thin walled and some base fragments from 16/02/10 (4), 18/02/10 (1) appear curved suggesting that they are most likely of type 2. The fragments from 21/02/10 (2) (5) (6) on the other hand have thicker walls (up to 21mm) and appear to come from larger crucibles suggesting that they are more likely to have been of type 1 or 3. A lid fragment was recovered from 18/02/10 (1) but cannot be [positively attributed to any type. It appears rounded like the type 2 and 3 crucibles but also has tongue marks like the type 1 crucibles.

26/01/10 (8)



16/02/10 (4)





17/02/10 (1)


21/02/10 (2)

21/02/10 (6)

18/02/10 (1)

Appendix C.7 – Coloured Glassy Slag

Many coloured glassy slag fragments were recovered during the Pioneering Metallurgy Project which seem to be associated with crucible steel production sites. Two main types are identifiable: a glassy green slaggy material (GS1) and a glassy black slaggy material (GS2). This section will describe these two main types of coloured glassy slags. Table 1 below shows the weight of the material found in each location categorised by type. All photographs relate to the text directly preceding them.

Table 1 - Weight in grams of the material collected in each location categorised by type.

Location	GS1 - Green Glassy Slag	GS2 - Black Glassy Slag
29/01/10 (1)	5	-
06/02/10 (2)	37	-
08/02/10 (1)	1350	-
08/02/10 (9)	856	-
09/02/10 (1)	42	-
09/02/10 (2)	515	-
09/02/10 (5)	-	54
10/02/10 (1)	1518	-
10/02/10 (2)	93	151
10/02/10 (3)	23	-
10/02/10 (4)	285	-
17/02/10 (2)	167	-
21/02/10 (2)	50	-
21/02/10 (3)	200	-
22/02/10 (1)	955	-
25/02/10 (1)	251	-
26/02/10 (5)	181	-
26/02/10 (6)	2040	-

Appendix C.7.1 – GS1

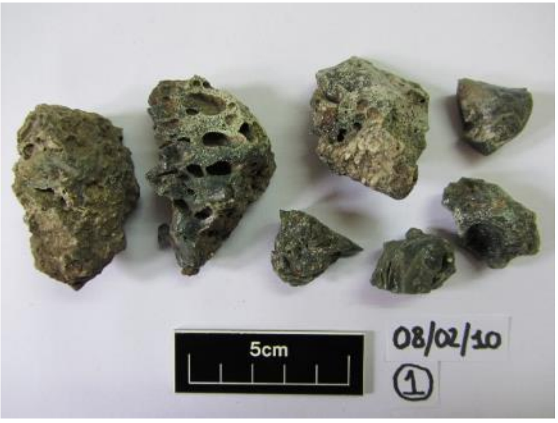
Colour	Matt pale green to dark glassy green
Characteristic features	Amorphous; rounded molten appearance; angular fractures; charcoal impressions
Size range	Most <50mm but up to 95mm. Amorphous.
Locations in which found	29/01/10 (1); 06/02/10 (2); 08/02/10 (1) (9); 09/02/10 (2); 10/02/10 (1) (2) (3) (4); 17/02/10 (2); 21/02/10 (2) (3); 22/02/10 (1); 25/02/10 (1); 26/02/10 (5) (6)

The green glassy slag recovered is mainly amorphous in shape and very fragmentary with most edges broken, angular fractures and smooth surfaces. However, some have natural edges remaining which show well-rounded projections of material as if they had flowed. The majority of fragments are very small, usually <55mm in size but there are a few larger pieces up to 128mm (in 08/02/10 (1) (9); 09/02/10 (2); 10/02/10 (1); 22/02/10 (1); 25/02/10 (1); 26/02/10 (6)) which seem to retain some of their original surfaces. Their colour range from a pale green to a shiny dark glassy green. In some cases, especially on the larger fragments, there are areas of dull whitish to yellowy-grey (sometimes medium to dark grey) which are medium sandpaper rough in texture (06/02/10 (1); 08/02/10 (1) (9); 09/02/10 (2); 10/02/10 (1) (2) (3) (4); 17/02/10 (2); 21/02/10 (3); 25/02/10 (1); 26/02/10 (5) (6)). These areas mainly occur on the fragments that have retained some original surfaces but some of the smaller fragments have patches on their broken edges. This resembles the dull whitish-grey material seen on some of the exterior surfaces of the crucibles and larger fragments (discussed in chapter 5.8). This material also has molten rounded features (almost rippled) and some charcoal impressions/voids (up to 50mm but mainly <25mm) meaning that it was subject to very high temperatures and partially molten. The green glassy slag and these whitish-grey areas seem to be the same material as they are well fused with a clear colour transition from dull whitish-grey to dull pale green and glassy dark green. Sometimes there are whitish-grey to dull pale green speckles in the glassy dark green parts. The green glassy slag is almost certainly the more vitrified parts of this material which appears to be a type of limestone or sandstone. In general the green glassy parts are very solid with few spherical voids mainly <2mm but up to 8mm in size while the whitish-grey areas are more porous with many spherical voids up to 22mm in size.

Since these glassy slags only occur on crucible production sites and have clearly been molten in the charcoal charge, this material must have been added or placed somewhere inside the crucible furnaces. Their general amorphous shape and plentiful charcoal impressions means that they are unlikely to be a product that came out of the crucibles but may have been part of the original raw material charge. The material may also have been added to the furnaces to help maintain the crucibles in place or protect them from the high temperatures. Another possibility is that they are remains of heavily vitrified furnace wall. The green glassy slag fragments from 22/02/10 (1) have large inclusions that resemble quartz crystals (<5mm) and in this case it seems probable that it came from the furnace wall or even quartzite.

06/02/10 (2)

08/02/10 (9)



08/02/10 (1)

09/02/10 (2)

10/02/10 (4)

17/02/10 (2)

21/02/10 (3)

22/02/10 (1)

26/02/10 (5)

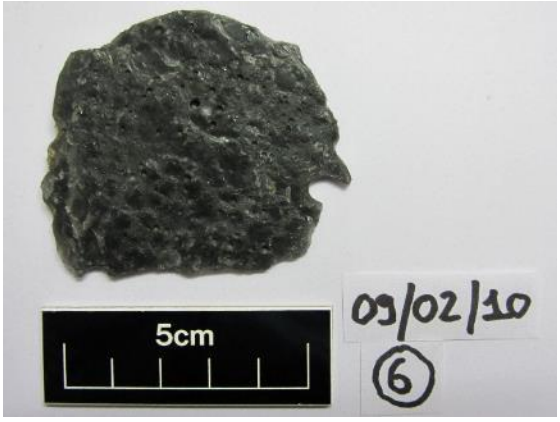
26/02/10 (6)

08/02/10 (1)

Appendix C.7.2 – GS2

Colour	Glassy black
Characteristic features	Thin; flat profile; smooth top surface; porous bottom surface
Size range	1-7mm thick and up to 66mm wide
Locations in which found	09/02/10 (5); 10/02/10 (2)

Several thin sheets of black glassy slag were recovered from locations 09/02/10 (5) and 10/02/10 (2). No fragment survives whole and they all have sharp angular fractured edges. These range in size from 1-7mm thick and up to 66mm wide although most fragments are <40mm wide. Most of these have one smooth and shiny, slightly convex side and a flat, slightly rougher porous side with spherical voids ranging in size from 1-6mm. It is very likely that these are the layer of black glassy slag that formed above the ingots inside the crucible as they are of the same composition as the slaggy fins adhering to the crucible sides. Indeed there are a few fragments which look like glassy fins being thicker and more triangular in shape with a convex surface on their thicker side. The thickest of which is approximately 11mm and must have come from a large crucible. In support of this theory is one fragment from 09/02/10 (5) which is 65mm at its widest and vaguely circular in plan. There are also a few fragments from 10/02/10 (2) which still have original convex edges with imprints of the crucible wall clay fabric. The smooth, slightly convex side is likely to have been the top of the glass while the more porous, flatter side being the underside which would have been in contact with the ingot. One of the larger slag fins in 10/02/10 (2) seems to have impressions of the ingot on its underside. Of interest is that some of the fragments are thicker on one edge suggesting that the glassy slag solidified at an angle. It is possible that some crucibles may have moved during firing. In some cases there are corroded magnetic metallic prills adhering to the smooth, curved top surface of the glassy slag. These are commonly found in the interiors of crucibles (see chapter 5.4).



09/02/10 (5)

09/02/10 (5)

09/02/10 (5)

10/02/10 (2)

10/02/10 (2)

10/02/10 (2)

Appendix C.8 – Ore

Many ore pieces were recovered during the 2010 Pioneering Metallurgy Project field survey. This section will deal with the main ore type descriptions. Table 1 below shows the quantity (weight and numbers), size range, colouration and magnetism of the ore fragments recovered at each location. All photographs relate to the text directly preceding them.

Table 1 - Table showing the quantity in weight (g) and No of fragments, size range (mm), colouration and magnetism of the ore pieces recovered from each location.

Location	Type (O)	Weight (g)	No.	Colour	Size (mm)			Magnetism
					L	W	T	
25/01/10 (4)	1	1033	2	Dark brownish red + dark yellowy brown – black bands	65 126	50 88	49 45	high
	1	240	1	Dark brownish purple	70	42	31	low
26/01/10 (1)	1	26	lot	black	<10			high
	1	130	1	Dark brown – thin black bands	69	32	23	mid
26/01/10 (3)	1	1940	2	Dark brownish red – black bands	79 115	58 95	49 43	mid/high
26/01/10 (4)	1	770	1	Dark reddish brown – black bands	113	54	71	mid
26/01/10 (7)	1	738	1	Dark greyish red – black bands	101	73	70	high
26/01/10 (8)	1	290	1	Dark brown – black bands	70	55	43	high
28/01/10 (3)	2	1336	8	Yellowy orangey brown – dark matt grey fractures	31-110	23-72	7-58	
28/01/10 (4)	1	179	lot	black	39 m <20			high
	1	300	5	Dark brownish red – black bands	16-53			mid
28/01/10 (5)	1	1980	1	Dark grey – black bands	173	109	67	high
28/01/10 (8)	1	1444	3	Black - shiny	<88			high
	1	6328	lot	Black – dark reddish orangey brown patches	<125			high
	1	149	lot	Dark orangey brown – black bands	<35			Low/mid
29/01/10 (5)	1	310	1	Brownish red/orange – black bands	81	52	38	low
01/02/10 (1)	1	690	2	Black bands – dark brownish orange patches	<84			mid
01/02/10 (2)	1	99	1	Dark reddish brown – black bands	46	25	26	high
	1	570	1	Dark brown + orangey patches – thin black bands	85			Low/mid
01/02/10 (5)	1	580	2	Dark brownish red – black bands	<83			low
01/02/10 (6)	1	220	1	Brownish yellow + dark grey/black patches	77			mid
01/02/10 (7)	1	648	7	Dark brownish red + dark grey – small black bands	<70			Low/mid
02/02/10 (1)	1	474	1	Dark greyish brown + dark reddish tinge – black bands	80	68	35	high
02/02/10 (4)	2	1630	1	Reddish yellowy brown + dark grey – thin elongated voids 35mm – molten	144	103	80	
02/02/10 (6)	1	702	2	Dark reddish brown – black speckles – yellowy brown quartz inclusions	55 98	50	26	high

Location	Type (O)	Weight (g)	No.	Colour	Size (mm)			Magnetism
					L	W	T	
02/02/10 (8)	1	442	1	Dark brownish red + dark grey – thin black bands	110	99	25	high
03/02/10 (1)	1	240	1	Dark grey – dark brown + orange	78			mid/high
03/02/10 (2)	1	230	1	Dark grey + dark red	75			mid/high
06/02/10 (3)	2	920	1	Dark reddish brown	121			
08/02/10 (8)	1	64	1	Dark brown – black bands	45	37	22	high
08/02/10 (9)	1	179	1	Dark reddish brown – yellowy brown + black bands	58	36	54	high
08/02/10 (11)	2	1630	1	Dark brownish red – black patches on fractures	149	68	73	
11/02/10 (6)	1	113	1	Dark reddish brown – black bands	45	37	27	high
12/02/10 (6)	2	640	1	Dark reddish brown – orange patches	103			
12/02/10 (10)	2	467	3	Dark brownish red + dark brownish yellow and black patches	39-78	27-70	24-52	
16/02/10 (4)	1	83	1	Dark reddish brown – black bands – very small shiny inclusions (<1mm)	47	35	20	high
18/02/10 (5)	1	920	8	Dark yellowy brown + dark brown + purplish red	<97			mid
19/02/10 (2)	1	410	1	Brown – dark red – black bands	96			Low/mid
19/02/10 (5)	1	629	6	Dark reddish brown/purple – black bands	31-96	35-	31-	high
22/02/10 (4)	1	330	1	Dark reddish brown – black bands	75			low
23/02/10 (1)	1	57	1	Black – shiny crystallisation on fractures	41	34	19	high
	2	160	1	Dark grey + dark reddish brown + yellowy brown	54			
23/02/10 (4)	1?	227	1	Dark yellowy brown – black bands	68	62	30	
23/02/10 (5)	1?	19	1	Dark brown – black bands	<35			low
23/02/10 (11)	2	661	1	Dark brownish red – many shiny quartz like inclusions (<1mm)	95	64	86	
23/02/10 (12)	1	190	1	Brownish orange + dark grey + brown	57			mid
25/02/10 (6)	1	18	2	Dark reddish brown	<20			high
	1	204	4	Dark yellow + reddish brown – thin black bands	43-95			low
26/02/10 (5/6)	1	930	1	Black – yellowy brown patches	93	86	48	high
27/02/10 (1)	1	330	7	Dark reddish brown – black bands	<57			mid/high
27/02/10 (6)	1	243	1	Dark brownish red – thin black bands	67	62	28	low
19/09/09 (7)	1	1910	4	Dark brown – dark reddish purplish brown + yellow patches – black bands	<127			high

Appendix C.8.1 - O1

General Characteristics	Black bands, dense and magnetic
Size Range	From <10mm to 173mm in maximum length
Magnetism	Mostly high but different grades present ranging from low to high magnetism.
Locations	25/01/10 (4), 26/01/10 (1) (3) (4) (7) (8), 28/01/10 (4) (5) (8), 29/02/10 (5), 01/02/10 (1) (2) (5) (6) (7), 02/02/10 (1) (6) (8), 03/02/10 (1) (2), 08/02/10 (8) (9), 11/02/10 (6), 16/02/10 (4), 18/02/10 (5), 19/02/10 (2) (5), 22/02/10 (4), 23/02/10 (1) (4) (5) (12), 25/02/10 (6), 26/02/10 (5/6), 27/02/10 (1) (6), 19/09/09 (7)

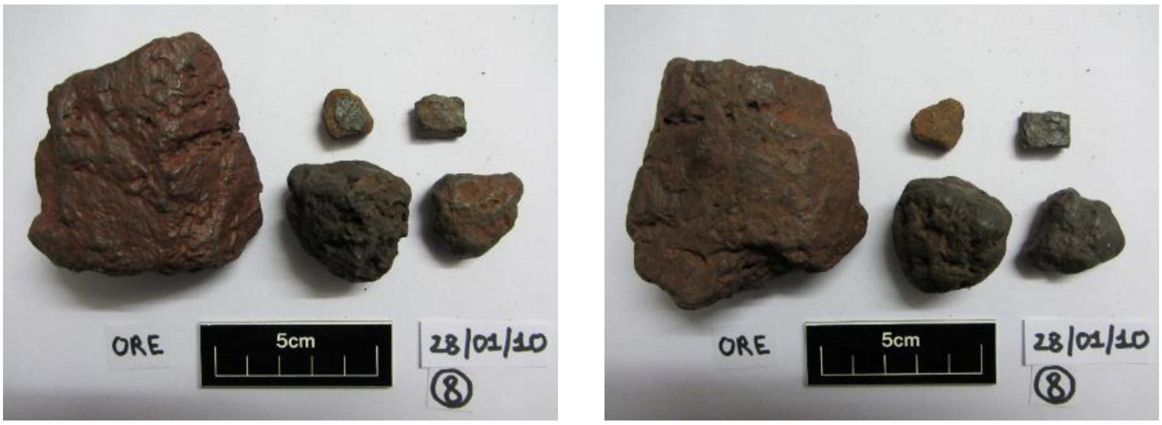
This is by far the most common ore type in the assemblage. Ores of this type were found in locations 25/01/10 (4), 26/01/10 (1) (3) (4) (7) (8), 28/01/10 (4) (5) (8), 29/02/10 (5), 01/02/10 (1) (2) (5) (6) (7), 02/02/10 (1) (6) (8), 03/02/10 (1) (2), 08/02/10 (8) (9), 11/02/10 (6), 16/02/10 (4), 18/02/10 (5), 19/02/10 (2) (5), 22/02/10 (4), 23/02/10 (1) (4) (5) (12), 25/02/10 (6), 26/02/10 (5/6), 27/02/10 (1) (6) and 19/09/09 (7). They range in size from <10mm to 173mm in maximum length. They vary in colour from dark brownish-red, yellowy-orangey-brown, dark brown, dark grey to black. The majority have smooth to low rough surfaces and have rounded edges as if they had been worn or abraded over time. Very few have sharp angular appearances. The majority also have clear black bands of different thicknesses running through them. These are very magnetic and undoubtedly have higher iron content. Combined with the fact that all pieces and fragments of this type are magnetic suggests that they are banded magnetite. Their magnetism varies considerably suggesting that a large proportion of the pieces collected are of low grade. The most magnetic and dense pieces are fragments recovered in locations 26/01/10 (1), 28/01/10 (4) (8), 23/02/10 (1), 25/02/10 (6), 26/02/10 (5/6) and 19/09/09 (7). These are usually quite small in size, homogenous, very magnetic and fully black in colour. They appear to be the same material as the black bands found on the other pieces of this type.

26/01/10 (3)

28/01/10 (4)

28/01/10 (5)

28/01/10 (8)



28/01/10 (8)


01/02/10 (5)


03/02/10 (2)

19/02/10 (5)

23/02/10 (4)

25/02/10 (6)

26/02/10 (5/6)

27/02/10 (6)

19/09/09 (7)

Appendix C.8.2 – O2

General Characteristics	Dark brownish red to yellowy orangey brown coloured dense fragments that are not magnetic
Size Range	From 31mm to 141mm in maximum length
Magnetism	Not magnetic
Locations	28/01/10 (3), 02/02/10 (4), 06/02/10 (3), 08/02/10 (11), 12/02/10 (6) (10), 23/02/10 (1) (11)

Potential ore fragments of this type were recovered from locations 28/01/10 (3), 02/02/10 (4), 06/02/10 (3), 08/02/10 (11), 12/02/10 (6) (10) and 23/02/10 (1) (11). The major characteristic feature which define them as this type are the fact that they are non-magnetic but still quite dense. It is uncertain what these geological pieces and fragments are but they appear to be iron ores, most likely hematite or laterite. The majority are angular with broken edges. They vary in size from 31mm to 141mm in maximum length and vary in shades of dark brownish-red and yellowy-orangey-brown as well as different shades of grey. Most are solid with no voids but some have very few spherical or globular voids. Their surfaces are usually flat and smooth to low rough in texture.

28/01/10 (3)

02/02/10 (4)


06/02/10 (3)

08/02/10 (11)


12/02/10 (6)

23/02/10 (11)

Appendix C.9 – Geological

Several geological fragments potentially associated with metallurgical technologies were recovered during the Pioneering Metallurgy Project 2010 survey. This section will deal with the descriptions of the different types of geological material recovered. Table 1 below shows the quantity (weight and numbers), size range, colouration and brief descriptions of the geological fragments recovered at each location. All photographs relate to the text directly preceding them.

Table 1 - Table showing the weight, quantity, size range, colouration and bried descriptions of the geological fragments recovered in each location.

Location	Type (G)	Weight (g)	No.	Colour	Material	Size (mm)		
						L	W	T
28/01/10 (1)	2	28	2	Greyish white + pale yellow patches	Limestone?	51 64	35 31	26 16
28/01/10 (2)	2	910	2	Greyish white + pale yellow patches	Limestone?	<100		
29/01/10 (1)	6	10370	1	Mid/dark grey + brownish orange patches + black vit	Granite?	315	214	115
01/02/10 (1)	1	6540	2	Brownish orange + mid/dark grey – dark grey/black vit	Granite/ quartzite?	201 224	111 206	102 48
01/02/10 (3)	1	4540	1	Brownish orange + mid/dark grey – dark grey/black vit	Granite/ quartzite?	196	212	105
01/02/10 (4)	1	1850	1	Light/mid grey – dark grey/black vit	Granite/ quartzite?	160	128	83
02/02/10 (5)	1	3170	1	Orangey brown + light/mid grey – dark grey/black vit	Granite/ quartzite?	236	187	80
02/02/10 (6)	1	4210	1	Orangey brown + light/mid grey – dark grey/black vit	Granite/ quartzite?	205	174	58
02/02/10 (8)	1	460	1	Light/mid grey + orangey brown patches – dark grey/black vit	Granite/ quartzite?	132	79	32
05/02/10 (1)	2	19	1	Greyish white	Limestone?	42	30	12
08/02/10 (9)	5	2300	1	Whitish grey + orangey patches	Granite/ quartzite?	226	80	90
12/02/10 (4)	3	1400	1	Greyish white + mid/dark grey patches	Limestone?	188	177	47
16/02/10 (5)	1	949	1	Whitish grey + orangey greyish light brown – dark grey/black patches	Quartzite?	126	114	57
16/02/10 (6)	4	176	4	Light/mid grey	Fine stone?	54-96	31-58	5-53
17/02/10 (3)	2	249	1	Whitish grey + pale yellowy brown tint	Limestone?	72	66	53
17/02/10 (5)	2	165	1	Mid/dark grey	Limestone?	61	55	46
17/02/10 (6)	4	250	1	Dark greyish red	?	80	62	46

Location	Type (G)	Weight (g)	No.	Colour	Material	Size (mm)		
						L	W	T
		308	1	Mid/dark grey + brownish red	pebble	89		21
19/02/10 (1)	2?	103	1	Very pale green tint + dark brownish red patches	?	52	31	32
21/02/10 (3)	3	159 816	5	Light/mid whitish grey + some dark glassy green and very pale green areas	Limestone?	<70- 103	100	71
21/02/10 (8)	3	60 805	2	Light/mid whitish grey + some dark glassy green and very pale green areas	Limestone?	<70- 101	105	80
27/02/10 (5)	5	735	1	Pale yellowy orangey mid grey + dark grey patches	Quartzite?	122	83	68

Appendix C.9.1 – G1

General Characteristics	Large stones surrounded by coarse clay with one vitrified side
Rock Type	Quartzite/granite?
Size Range	From 132x79x32mm to 236x187x80mm
Locations	01/02/10 (1) (3) (4), 02/02/10 (5) (6) (8), 16/02/10 (5)

Several geological fragments/pieces of this type were recovered from locations 01/02/10 (1) (3) (4), 02/02/10 (5) (6) (8) and 16/02/10 (5). These are all very similar and comprise of a large quartzite or granite rock/stone with adhering clay. These were probably part of a furnace structure whereby large stones were placed in the furnace walls. The remaining fragments (including the adhering clay) range in size from 132x79x32mm to 236x187x80mm. The majority of the stones look whole except those found in locations 01/02/10 (3) (4) and 02/02/10 (5) which have broken fractures. These look reasonably fresh and appear to have occurred after deposition. The rocks are either quartzite or granite but this cannot be positively ascertained. The rocks vary in colour from brownish-orange or orangey-brown to varying shades of mid to dark grey.

Their major characteristic is that they all have one vitrified side whereby a thin layer/coating of clay vitrification is present. This vitrification is no more than 10mm thick but sometimes extends beyond the edge of the stones as if they had been surrounded by clay with the interior surface becoming vitrified. The vitrification is dark grey to black in colour sometimes with dark brownish-red patches. It tends to be rough and agitated with small, sharp, broken protrusions of material. In some cases, charcoal impressions (up to 40mm) are noticeable but these remain few. In some areas the vitrification is flatter and smoother and could contain slag (but hard to determine). The vitrified surfaces have some porosity with spherical and irregular voids up to 16mm but most <10mm. In some cases small partially melted white quartz crystals can also be seen on the surfaces. The two fragments from 01/02/10 (1) and the one from 02/02/10 (5) have a curved vitrified depression which extends beyond the stone like a lip. These appear to have been more molten and have some glassy black areas.

The back sides (or non-vitrified sides) have no vitrification present except some minor thin vitrification present on the one found in 02/02/10 (6). This may be indicative of the stone’s re-use. All other stones are bare with no adhering clay or vitrification. It is possible that the clay broke off after deposition but the back side of the stones could also have protruded from the furnace wall. One of the rocks from 01/02/10 (1) appears to have a line of slag on the back side with small patches of heavily reduced dark grey clay. It is likely that the rock was placed in the wall (fully surrounded by clay) and that slag ran through the clay around the stone to solidify on the back. It is also possible that this rock formed part of the wall base. Most examples have some remains of dark grey reduced clay still adhering to the sides. This clay is mostly coarse to very coarse dominated by quartz crystals up to 10mm but mostly <5mm in size. The clay on the stone from 02/02/10 (6) is dark reddish-orange on the back but graduates to dark grey closer to the vitrified side. The vitrification on the stone from 16/02/10 (5) is interesting as it is concentrated on one edge of the stone. It is <2mm thick with possible remains of slag. It covers one whole edge but no others and it has a small vitrified lip (<5mm) on what may be the top edge of the stone presumably where the furnace wall would have been. That edge also appears to be curved (concave) but only a small part of it survives as the stone is broken. It is very likely that this was part of a larger stone fragment used as a stone base for the furnace wall.

Most of the stones appear to have not been shaped except perhaps one from 01/02/10 (1) which seems to have some surface pitting. These stones where likely placed in furnace walls or were part of furnace bases. They may have been used to support or reinforce the clay structures or provide steadier bases on which the structures were built.

01/02/10 (1)

01/02/10 (1)

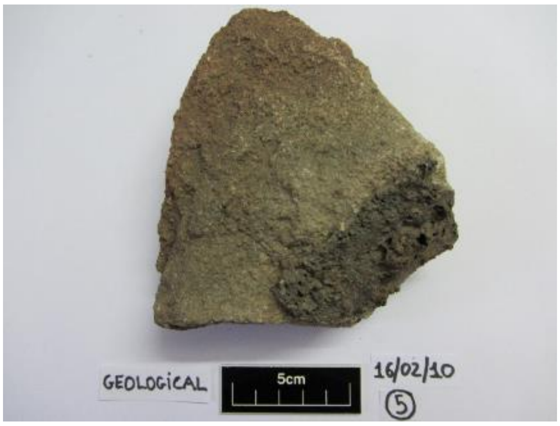
01/02/10 (3)

01/02/10 (4)

02/02/10 (5)

02/02/10 (6)

02/02/10 (8)



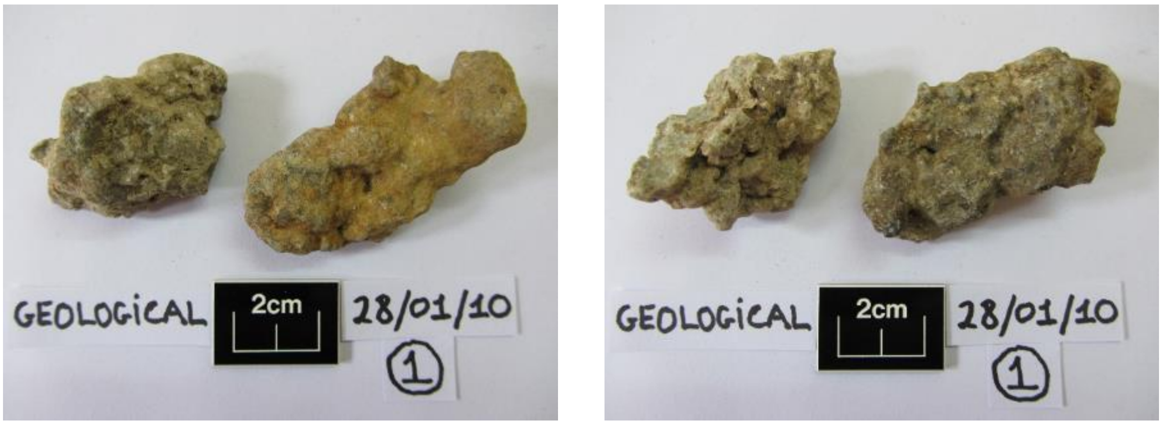
16/02/10 (5)

Appendix C.9.2 – G2

General Characteristics	Small amorphous complete bulbous limetone? pieces
Rock Type	Limestone?
Size Range	From 42x30x12mm to max 100mm in length
Locations	28/01/10 (1) (2), 05/02/10 (1), 17/02/10 (3) (5), 19/02/10 (1)

Several geological pieces of this type were recovered from locations 28/01/10 (1) (2), 05/02/10 (1), 17/02/10 (3) (5) and 19/02/10 (1). These range in size from the smallest piece 42x30x12mm to the largest at 100mm in maximum length. Most pieces appear to be complete. They are amorphous in shape and bulbous with rounded and smooth projections. They vary in shades of greyish-white with pale yellow and brown patches. The grain appears to be fine and the surfaces are smooth to low rough (sandy/chalky texture). Most are solid with no to very little porosity. It is uncertain what kind of stone they are but they look like hard inclusions (nodules) found in limestone or chalk. They may have been added to the furnace charge as a flux or maybe they were pieces intentionally removed from larger limestone fragments. Since none of the geological pieces of this type show any signs of having been burnt or used in the metallurgical processes under study, it is possible that they occur naturally and have no correlation to the metallurgical activities.

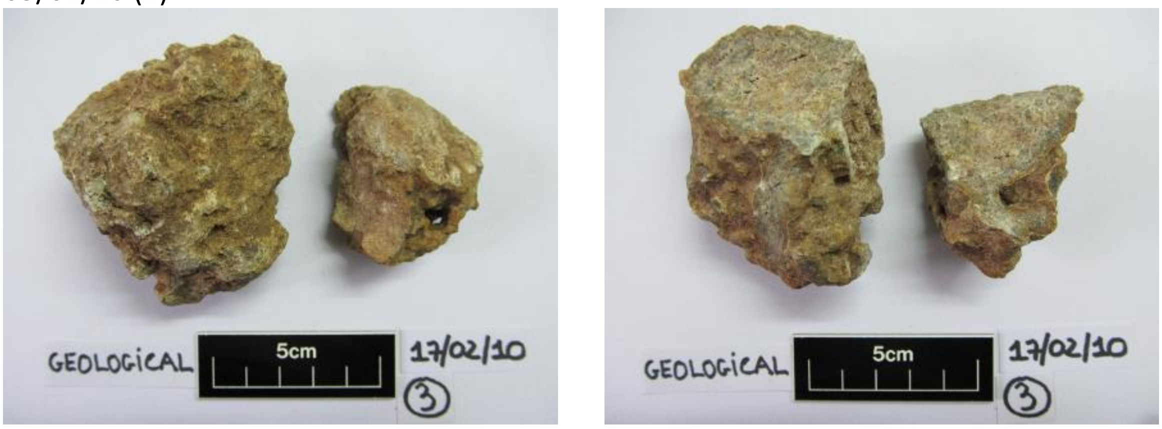
The fragment from 19/02/10 (1) differs slightly from the other pieces of this type. It is 52x31x32mm in size and very angular as if the edges had been broken. The fragment itself has a very pale green tinge to it and has many dark brownish-red patches which must be soil staining. The fragment is slightly porous with some globular and irregular voids mainly <3mm randomly scattered. One side appears to be an original surface and is undulated with many small rounded protrusions. It is hard to identify what kind of rock this might be but the greenish colour may indicate that it was subject to high temperatures and may even have been used as a flux. This cannot be ascertained though.



28/01/10 (1)


28/02/10 (2)

05/02/10 (1)



17/02/10 (3)

17/02/10 (5)

19/02/10 (1)

Appendix C.9.3 – G3

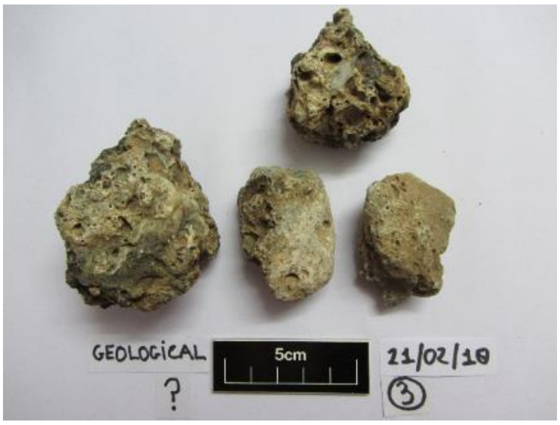
General Characteristics	Molten material with some porosity and lots of charcoal impressions
Rock Type	Limestone?
Size Range	From <70mm to 188x177x47mm
Locations	12/02/10 (4), 21/02/10 (3) (8)

This type comprises of light to mid grey vitrified/molten rock or ceramic. The general characteristics are that this rock (perhaps sand/limestone or fully vitrified coarse ceramic) is well molten with rounded features and lots of large charcoal impressions. Five fragment of this material were recovered from 21/02/10 (3) and two from 21/02/10 (8). Out of these there are only two large fragments, one from each location. The rest are smaller than 70mm in size and are clearly broken fragments very similar to the larger ones. It is evident that all fragments have a high proportion of charcoal impressions (up to 30mm) and are quite porous with many mainly spherical or globular voids mainly varying in size from <1mm to 10mm. As mentioned before the dominant colour is a white to mid grey but there are some patches which are clearly a dark glassy green or even some that are very pale green. All the fragments are not complete and are broken on edges making angular breaks adding to the agitated look but some are smoother and more rounded and must represent original surfaces. These parts are the ones that are whiter and feel like fine limestone in texture. On some fresh breaks on the smaller fragments clear partially melted quartz crystals are apparent and it is unknown if this type of material resulted from the vitrification of the furnace walls or whether something was added to the furnace to either act as a flux (do not know why since crucibles are mainly contained) or perhaps to reduce the impact of heat on the crucible walls or even to help keep crucibles separated or upright during the process. At this stage it is definite that this material was part of the crucible steel process but its identification and function remain to be ascertained.

The larger fragments are both very interesting. The one from 21/02/10 (3) is 103x100x71mm in size and although mostly broken it does appear to have one original surface made of this limestone textured white material. The curious thing is that even the other side of the fragment is dominated by charcoal impressions meaning that this was unlikely to have been a furnace wall unless it was used as a divider to compartmentalise certain parts of the furnace. More likely it was just material present in the furnace itself surrounded by charcoal and presumably the crucibles. The broken side also has a large proportion of dark green glassy slaggy material and there are at least two rounded rusty metallic (magnetic) prills 5mm and 7mm in diameter. This reinforces the idea that these were used in the crucible process and the prills may have escaped through the holes in the lid. A fresh fracture on this fragment reveals a very light pale green colour and heavily crystallised composition.

The other large fragment from 21/02/10 (8) is similar on one side but is clearly a furnace lining fragment (or at least definitely clay ceramic). It is 101x105x80mm in size and it is mainly composed of mid to dark grey reduced ceramic. This ceramic is coarse to very coarse dominated by small to large quartz crystals (most are <3mm but there are a few as large as 22mm). These quartz crystals may even be crushed quartzite. Of special interest is the side that is very vitrified. It looks almost like the fragments of possible melted sand/limestone. That side shows heavy mainly light grey but also some dark grey vitrification dominated by large and deep charcoal impressions (up to 37mm). It is unknown whether this was partially caused by the potential flux added into the furnace like seen above or if this is just the vitrified furnace wall lining. In this case the progression of vitrification from the reduced clay side to the charcoal impressed vitrified side would suggest that it is mainly vitrified ceramic. In support is the fact that some fresh breaks on the vitrified side appear to show partially reduced quartz crystals which would be consistent with the ceramic fabric. The ceramic fragment is broken on all sides and is otherwise non-diagnostic. The vitrified side does have some porosity with many tiny to small spherical voids (most <3mm). This fragment is interesting as it raises the question of this material actually is. Is it part of the furnace wall that has melted beyond recognition or is it a flux or addition to the furnace? In the last case it is likely to be melted wall but in the others it is far from certain as they look more like sand/limestone.

21/02/10 (3)



21/02/10 (3)

21/02/10 (8)

21/02/10 (8)

A large slab of limestone-like greyish-white material was also found in location 12/02/10 (4). It may be some of the material which turns to green glass when vitrified found at many crucible locations. The slab is 188x177x47mm in size and is quite porous with some spherical and globular holes scattered on the surface (most <10mm). There are also a significant proportion of charcoal impressions up to 25mm which adds to the rough and porous appearance. There are two crucible fragments on one side and another on the other side. These appear to be side or body sherds and the fact that there are remains on both sides suggests that it was standing upright in the furnace and unlikely to have been a base (unless it was reused and the crucibles fell onto their sides). One side appears to be more broken than the other whereby most of the protrusions are broken while the other seems quite complete with less porosity but still a few charcoal impressions and a rough undulated texture. It is reasonably flat on that side though suggesting that it solidified on a hard surface. It is possible that this material was added to the furnace and melted to form a layer on the bottom of the furnace. All the sides are broken revealing more charcoal impressions and one largish metallic (steel?) prill. There are a few small (<13mm) clay inclusions which vary from reduced dark grey to oxidised bright orange. These seem to be of a sandy friable type similar to the clay fragments found in 12/02/10 (3) and (4).



12/02/10 (4)

Appendix C.9.4 – G4

General Characteristics	Potential ornamental shaped stone fragments
Rock Type	?
Size Range	From 54x31x5mm to 96x58x53mm
Locations	16/02/10 (6), 17/02/10 (6)

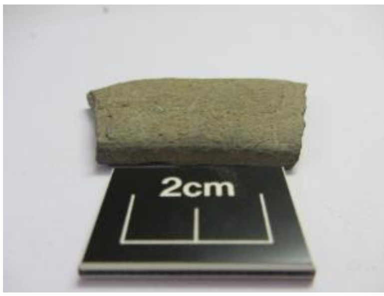
In total, five stone fragments of this type were recovered. Four were found at location 16/02/10 (6) and one at location 17/02/10 (6). The largest fragment from 16/02/10 (6) is an angular stone 96x58x53mm in size. It has no heat or vitrification marks and may just be a regular stone. There is no evidence of clay nor any visible intentional alteration. The surfaces are flat and smooth with small fracture marks making them slightly uneven. The stone is light to mid grey in colour and appears to be fine grained. The small chips reveal that the inside is of a pale purple colour and fine.

The two next largest fragments from 16/02/10 (6) are similar to one another. They are small (<70mm in length and <40mm wide) and are rounded smooth all over. These may also be natural as there are no evident signs of having been intentionally shaped. The smoothness may have been caused by polishing of the stone but this cannot be certified. The smaller fragment has two small depressions on one side which is not too dissimilar from some of the sharpening stones used in the area but they seem too well rounded. They are also light to mid grey in colour and seem to be a similar stone to the larger angular fragment. The smallest fragment from 16/02/10 (6) is more interesting. It is 54x31x5mm in size and is reasonably smooth with flat surfaces. It is thin and the edges are rounded on the two longest sides with fractures at both ends. One surface is more rounded than the other and it is possible that this was used as a sharpening whetstone. There are some straight marks on one side which may have been caused by sharpening but it cannot be certified for sure. It is also light to mid grey and may be the same type of stone as the other fragments.

The fragment of stone from 17/02/10 (6) is broken on all sides except one. This side is perfectly rounded like if had been shaped and polished. The stone is 80x62x46mm in size and of a dark greyish-red colour. The broken edges make it very angular. It has a medium grain structure (about 2mm) and could be quartzite although hard to tell. This fragment may have been part of a structure or sculpture but it could also just be a broken pebble.

16/02/10 (6)

16/02/10 (6)



16/02/10 (6)

17/02/10 (6)

Appendix C.9.5 – G5

General Characteristics	Angular rocks – no evidence of having been burnt or used in metallurgical processes
Rock Type	Granite/quartzite?
Size Range	122x83x68mm and 226x80x90mm
Locations	08/02/10 (9), 27/02/10 (5)

Two large angular rock fragments were recovered. The largest one was found in location 08/02/10 (9). It appears to be granite or quartzite but it is hard to tell. It is 226x80x90mm in size with two flat sides and one side that appears broken. It also seems to be curved and may have been part of a quern stone that has broken (two fractures are present at both ends). The top flat side (or what I gather to be the top) has an orangey tint to it and could suggest that the base of a furnace wall was built on top (like the type 6 example). That surface is about 80mm wide and could easily have sustained the type of elephant foot base wall that were found at the site. The rest of the stone are different shades of whitish-grey with a clear large/coarse granular texture. The underside is broken and this may have been intentional in order to shape the stone for the furnace structures but it may also have broken due to the high temperatures reached in the furnace. It is hard to say whether the stone has been subject to high temperatures but the fact that it is mid to dark grey on one side may be indicative. However, there is no slag or vitrification adhering to the stone. Therefore it cannot be proved whether or not this fragment was used as a furnace base. It is possible that it was lined with clay which has chipped off.

The other fragment was recovered from 27/02/10 (5) and appears to be quartzite. It is quite angular and 122x83x68mm in size. Most of the sides are fractured and reveal the quartzite grains but there are a few smoothish sides with angular edges which may have been manmade but hard to tell. There is no evidence of burning or vitrification. Maybe it is a part of a statue or a grinding tool or it could just be natural. It is mainly pale yellowy-orangey-grey in colour with some dark grey patches.

08/02/10 (9)

27/02/10 (5)

Appendix C.9.6 – G6

General Characteristics	Unique granite furnace base with central depression and vitrified clay within this depression
Rock Type	Granite
Size Range	315x214x115mm
Locations	29/01/10 (1)

A unique geological fragment was found at location 29/01/10 (1). It appears to be made of granite but could also be quartzite. It is 315x214x115mm in size and looks like a semi-circle in plan with a depression in what would have been the centre of the circle. It is most likely a fragment (almost half) of a round furnace base, as the edges appear to have been broken.

The depression is covered with a slaggy ceramic vitrification. This vitrification is black but covered in brown staining which may be from the soil; it is reasonably smooth but knobbly with distinct flows (going down the depression). The vitrification extends beyond the granite in the depression suggesting that it must have been a hole. This depression is surrounded by a flattish platform on the periphery of the stone (about 80mm large). This platform has brownish-yellowy-orange staining (the colour of dried clay) suggesting that the furnace wall was built on top, perhaps explaining the vitrified clay running on the inside of the depression.

The stone itself seems to have been shaped as there are distinct small pits all over the surface as if small amounts of material have been chipped off. This is especially evident on its flat base. It is unknown however, whether this furnace base was specifically shaped for metallurgical production or whether it had been recycled, for example, an old quern (which it resembles) that had been used till a hole appeared and hence could no longer be utilised for that purpose.

A further note is that the slaggy vitrification has large inclusions of what looks like quartz which are very similar to the inclusions found in the furnace lining from this area. In support of this is the fact that the curved furnace lining remains match the curvature of the stone perfectly and in the case of the rounded and curved un-vitrified fragment (from the same location) not only is the curvature identical but the width of the clay matches the width of the platform exactly. The vitrification also has very few small (<10mm) charcoal impressions.

Another interesting point is that the slaggy vitrification appears to be just that (with no slag apparent) suggesting that this furnace was more likely used for the production of crucible steel. The interior of the furnace is likely to have been around 300mm in diameter.

29/01/10 (1)

Appendix C.10 – Metallic Iron

Several potential metallic iron fragments were recovered during the 2010 Pioneering Metallurgy Project. Several types were identified and these will be described in this section. Table 1 below shows the metallic iron quantification in weight (grams) and maximum size (mm) for each location. All photographs relate to the text directly preceding them.

Table 1 - Weight (grams) and maximum size (mm) of the metallic iron fragments by location.

Location	Type (I)	Weight (g)	No	Size (g-max)	Magnetism
25/01/10 (6)	2	50	1	38	High
01/02/10 (8)	2	50	3	<48	High
03/02/10 (1)	2	11	2	<20	Medium
03/02/10 (3)	1	466	1	105	High
03/02/10 (11)	2	57	1	83	Medium
05/02/10 (3)	3	392	1	121	Medium patch
08/02/10 (11)	4	13	1	60l 9w 6t	High
09/02/10 (6)	3	61	2	71	Low – medium patch
12/02/10 (1)	4	6	4	62l 10w 4t	High
	2	48	many	<30	High
	2	123	7	<40	High
	3	299	3	<70	High
	3	212	many	<60	Medium to High
	2	182	many	<40	High
12/02/10 (2)	3	254	3	81	High
	2	19	1	<40	High
12/02/10 (6)	2	117	1	44	High
13/02/10 (15)	2	91	1	52	High
15/02/10 (3)	1	82	1	58	High
16/02/10 (1)	1	194	1	84	High
16/02/10 (3)	4	29	1	24w 2t	High (iron band)
21/02/10 (5)	2	13	1	<35	Low
23/02/10 (5)	1	52	1	47	High
23/02/10 (12)	3	62	3	<50	Low
24/02/10 (1)	2	82	3	<30	High
	3	506	4	<80	High – medium patches
24/02/10 (3)	4	112	1	166l 27w 9t	High
	3	41	2	<40	High
25/02/10 (1)	2	49	6	<35	High
	3	39	1	42	Medium
	4	13	1	20w 3t	High (Iron band)
25/02/10 (4)	3	71	1	82	High
26/02/10 (1)	2	184	many	<55	High

Location	**Type (I)**	**Weight (g)**	**No**	**Size (g-max)**	**Magnetism**
26/02/10 (5)	2	86	many	<35	High
26/02/10 (8)	2	106	many	<40	High
27/02/10 (1)	2	13	1	26	High
27/02/10 (3)	2	49	2	<40	High
27/02/10 (5)	2	31	many	<20	High
27/02/10 (6)	2	100	3	<45	High
27/02/10 (7)	2	37	4	<20	High

Appendix C.10.1 – I1

Characteristic features	Dendritic/coral iron formation, complete pieces
Size range	47-105mm max length
Magnetism	High
Locations in which found	03/02/10 (3), 15/02/10 (3), 16/02/10 (1) and 23/02/10 (5)

Four dendritic iron bloom pieces were recovered from locations 03/02/10 (3), 15/02/10 (3), 16/02/10 (1) and 23/02/10 (5). The fragment from 03/02/10 (3) is the largest being 105x84x50mm in size; the one from 15/02/10 (3) is 58x35x26mm; the one from 16/02/10 (1) is 84x60x43mm and the one from 23/02/10 (5) is 47x32x18mm in size. They are all amorphous in shape with no clear top or bottom surfaces. They are also very dense and highly magnetic suggesting that they contain a large quantity of metallic iron. The fragments from 03/02/10 (3) and 16/02/10 (1) are the largest and most dendritic (coral like appearance) dominated by rounded (sometimes sharp) projections of material (most likely iron). The fragment from 23/02/10 (5) is also similar but a lot smaller. The fact that it is very dense and highly magnetic with some rounded projections suggests that it formed in a similar fashion as the larger examples. They are undoubtedly iron bloom fragments that formed inside a bloomery furnace. These iron formations were likely made through the consolidation of small dribbles or flows of partially malleable iron inside the furnace structure. All these iron pieces appear complete or almost complete but seem very small to represent the main bulk of the iron produced in a single smelting event. This suggests that they likely consolidated and solidified isolated from the main bloom or that they formed on the extremities of the bloom and broke off during removal or handling/refining. Whether or not these iron pieces were deliberately rejected is unknown.

Their surfaces are very similar to one another. They are all dark grey in colour but dominated by patches varying in shades of dark red and yellowy-orangey-brown. These patches are most likely due to the oxidisation of the more metallic parts close to the surface and perhaps even some soil staining. Most of these iron pieces appear to be covered in a thin layer (coating) of dark grey slag which probably protected them from any heavier oxidisation (corrosion) damage. The surfaces are medium rough to rough in texture often with very small sharp protrusions of material. The fragment from 16/02/10 (1) in particular is rough in texture with larger angular projections and its surface is almost entirely covered in orangey-brown corrosion adding to this roughness. Some of the surfaces in between the rounded dendritic projections appear to have faint charcoal impressions identifiable by their linear (wood grain) marks left in the surface slag coating. Indeed, in some cases the voids or gaps in between these projections (especially in the piece from 16/02/10 (1) are angular which suggests the iron may have formed and solidified around the charcoal charge inside the furnace.

All iron pieces are solid with no or very few voids. However, the fragment from 15/02/10 (3) differs slightly from the others. It appears to have more slag content on one side. Half of the fragment has the typical dendritic rounded projections typical of this iron type but the other side seems to have been broken revealing a thicker slag layer. This side is medium rough and of low porosity with few spherical and globular voids <5mm in size.

03/02/10 (3)

15/02/10 (3)

16/02/10 (1)

23/02/10 (5)

Appendix C.10.2 – I2

Characteristic features	Amorphous, dense, highly magnetic lumps
Size range	Up to 83mm max length but mostly <40mm.
Magnetism	Mostly high but a few medium
Locations in which found	25/01/10 (6), 01/02/10 (8), 03/02/10 (1) (11), 12/02/10 (1) (2) (6), 13/02/10 (15), 21/02/10 (5), 24/02/10 (1), 25/02/10 (1), 26/02/10 (1) (5) (8), 27/02/10 (1) (3) (5) (6) (7)

Iron fragments of this type are the most common in the assemblage. These are usually small, amorphous in shape, dense and medium to highly magnetic. The largest piece is 83mm in maximum length but the majority of the fragments are <40mm in maximum length. Iron of this type was recovered in locations 25/01/10 (6), 01/02/10 (8), 03/02/10 (1) (11), 12/02/10 (1) (2) (6), 13/02/10 (15), 21/02/10 (5), 24/02/10 (1), 25/02/10 (1), 26/02/10 (1) (5) (8) and 27/02/10 (1) (3) (5) (6) (7).

Most of these small iron pieces appear whole and could have been iron that formed in the furnace isolated from the main bloom or products resulting from smithing waste. Some may have been broken but due to the high level of surface corrosion of some of the fragments it is hard to tell. The majority are amorphous in shape with no clear top or bottom surface. All pieces are solid with no apparent voids. They are dense and for the most part highly magnetic. They range in colour from dark grey to varying shades of dark reddish-yellowy-orangey-brown. This colour was most likely caused by the oxidisation (corrosion) of the metal and indeed fragments/pieces from locations 03/02/10 (1) (11), 12/02/10 (1) (2), 25/02/10 (5) and 27/02/10 (1) appear to be almost fully corroded. Some of these more corroded lumps have cracked surfaces proving that the corrosion runs deep. The surfaces are for the most part low to medium rough with very small rounded projections suggesting that the iron pieces may have been abraded considerably after deposition. In some instances there are very small to small sharper protrusions making the surfaces more uneven and rougher to the touch.

Of special interest are some fragments/lumps from locations 03/02/10 (11) and 12/02/10 (1) (6). These have one or more flattened sides. This is unusual as all other fragments are amorphous and have uneven surfaces. This suggests that these iron lumps may have been smithed; the flattened sides being the result of the hammer hitting the heated metal. It is possible that small fragments of iron like these broke off larger blooms during refining. In support of this is the fact that these flattened surfaces appear to be cracked which may have been caused by the impact of the hammer during smithing. It is well known that hammerscale (oxidised iron flakes) and larger smithing flats detach from the surfaces of bloomery iron during the refining (smithing) process. The fragment from 12/02/10 (6) also appears to have very small quartz grains (<1mm) on one side suggesting that it either broke off during smithing to rest against the hearth lining or that sand was used as a flux during the smithing process. The fragment from 13/02/10 (15) is interesting because it has one spherical prill (probably spherical hammerscale) and what seems to be small hammerscale flakes on its surface. This suggests that at least this small lump was created or detached during the smithing process.

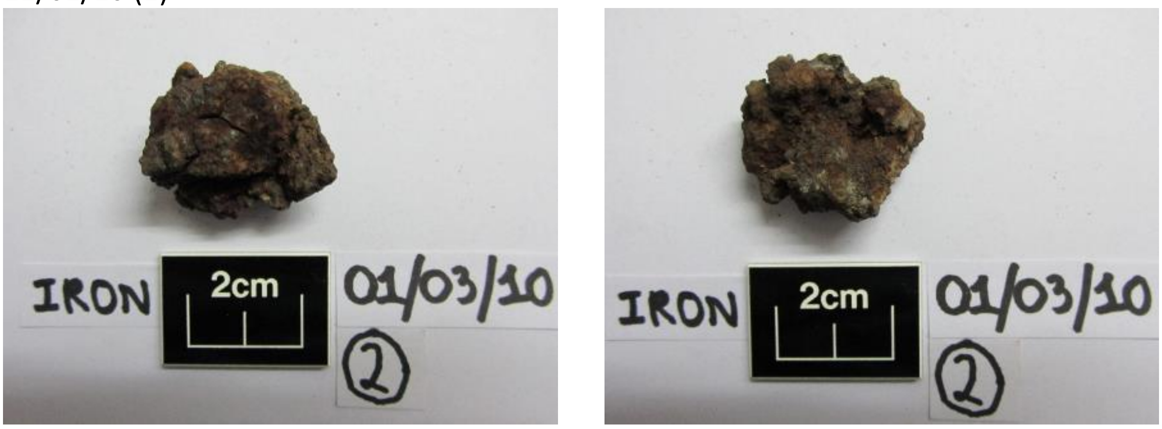
03/02/10 (1)

03/02/10 (11)

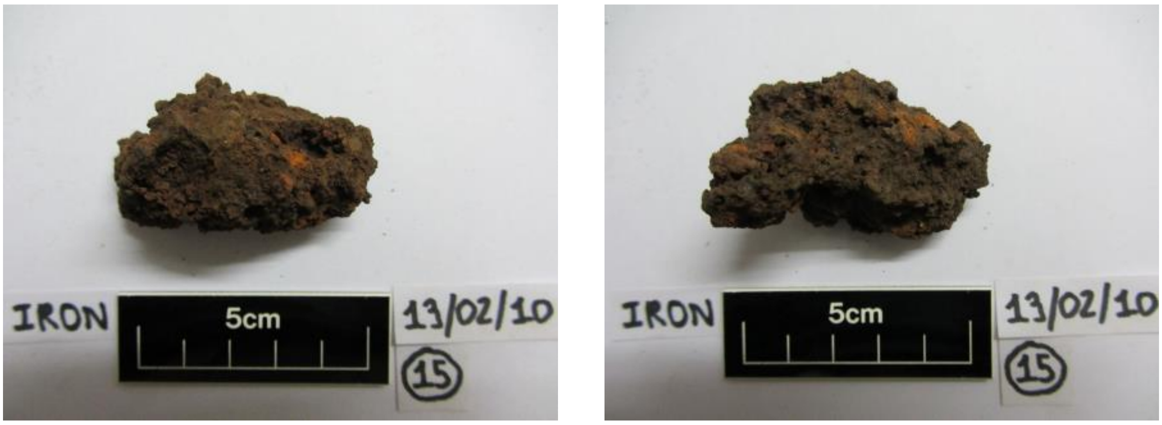
12/02/10 (6)

12/02/10 (1)

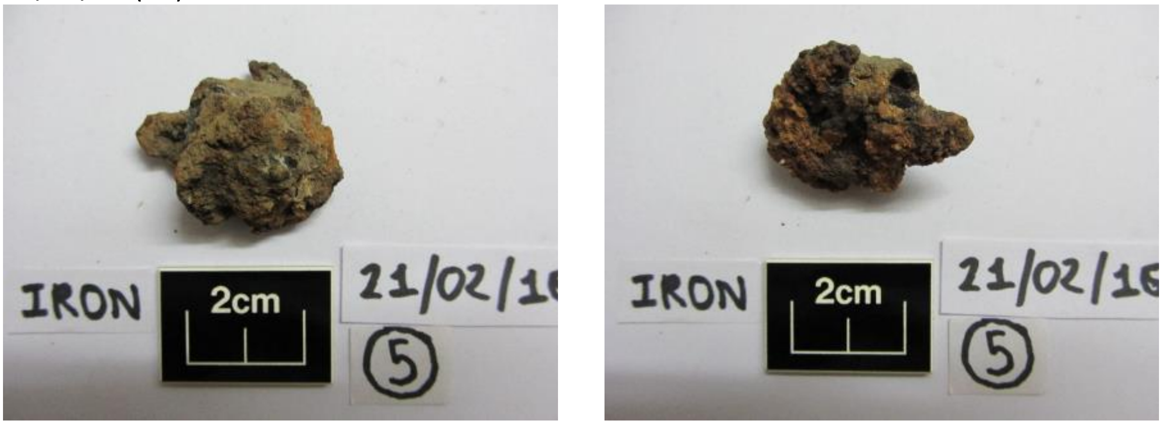
12/02/10 (1)



12/02/10 (2)



13/02/10 (15)



21/02/10 (5)

25/02/10 (1)

26/02/10 (1)

26/02/10 (5)

26/02/10 (8)

27/02/10 (1)

27/02/10 (3)

27/02/10 (5)

27/02/10 (6)

27/02/10 (7)

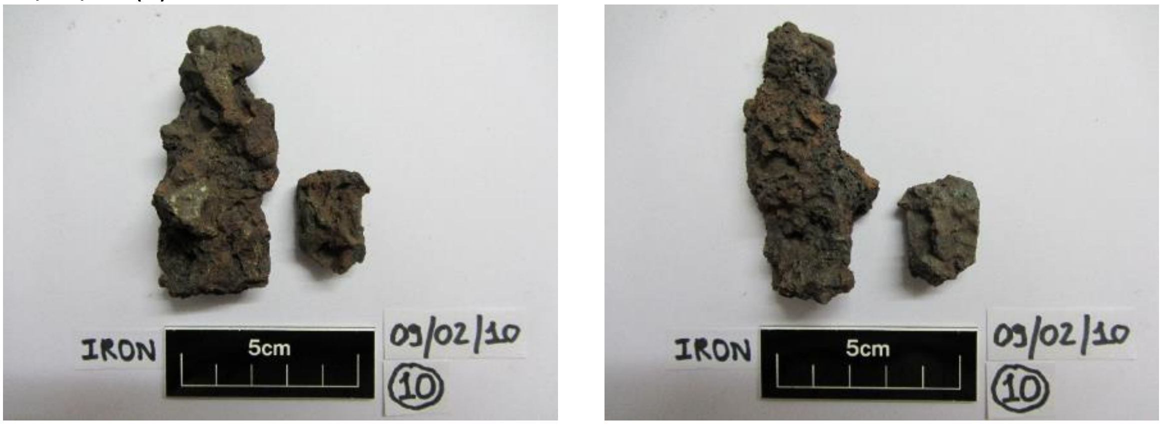
Appendix C.10.3 – I3

Characteristic features	Iron rich slag fragments
Size range	Up to 121mm max length but mostly <80mm
Magnetism	Mostly medium to high but some low
Locations in which found	05/02/10 (3), 09/02/10 (6), 12/02/10 (1) (2), 23/02/10 (12), 24/02/10 (1) (3), 25/02/10 (1) (4), 27/02/10 (6)

Many iron rich slag fragments were recovered in the assemblage. These are similar to many of the slag types described in the slag section but they differ in that they are either fully or partially magnetic. This means that they contain a high proportion of metallic iron. The fragments are usually small <80mm in maximum length but they can reach up to 121mm. The majority of these slags likely formed and solidified in the furnace but some may have been formed by the smithing (refining) process. Iron rich slags of this type are found in locations 05/02/10 (3), 09/02/10 (6), 12/02/10 (1) (2), 23/02/10 (12), 24/02/10 (1) (3), 25/02/10 (1) (4) and 27/02/10 (6).

Most of the fragments of this type are amorphous in shape with no clear top or bottom surface. The majority are also broken on some edges meaning that they would have been part of larger cakes of slag. The intact surfaces are all typical of slag with uneven usually well melted rounded projections of material (sometimes agitated like in the fragment from 05/02/10 (3). Most are mid to rough in texture with many small sharp projections. Many have charcoal imprints on their surfaces; this with the fact that they are amorphous with uneven surfaces suggests that most are probably furnace slag. The broken surfaces are usually rougher in nature with sharp broken projections. Most appear to be solid but there are some (especially from locations 05/02/10 (3), 09/02/10 (10), 12/02/10 (2), 23/02/10 (12), 24/02/10 (1) (3) and 25/02/10 (4) that have some small spherical and globular voids <10mm in size. They are mainly dark grey or dark greyish blue in colour with patches varying in shades of dark red and orangey-yellowy-brown. These patches may be corrosion of the more iron rich parts or soil staining. Most fragments are highly magnetic or have highly magnetic patches but some of the fragments from 09/02/10 (6) and 23/02/10 (12) are less magnetic. It has been noticed that the more magnetic areas of the slag fragments are often of a dark red/purple or orangey brown colour.

05/02/10 (3)



09/02/10 (6)

12/02/10 (1)

23/02/10 (12)

24/02/10 (1)

24/02/10 (3)

25/02/10 (4)

Appendix C.10.4 – I4

Characteristic features	Iron artefacts
Size range	Variation – see individual artefacts
Magnetism	High
Locations in which found	08/02/10 (11), 12/02/10 (1), 16/02/10 (3), 24/02/10 (3), 25/02/10 (1)

Five iron artefacts were recovered from locations 08/02/10 (11), 12/02/10 (1), 16/02/10 (3), 24/02/10 (3) and 25/02/10 (1). They all vary in shape and size but the fact that they are highly magnetic suggest that they are indeed iron. Their surfaces are all very corroded (oxidised) and vary in shades of dark red/purple and orangey yellowy brown. Due to the fact that they are artefacts (finished products) found on the ground surface and not production waste, it is not possible to determine whether or not they are contemporary with the iron production at these locations.

A small piece of shaped corroded iron 60x9x6mm in size was recovered from location 08/02/10 (11). The iron piece appears to be broken at its thickest end. The thickness of the artefact gradually diminishes to finish at a point. It is probably a nail.

08/02/10 (11)

A small piece of heavily corroded iron artefact 62x10x4mm in size was recovered from location 12/02/10 (1). Due to the heavy surface corrosion it is not diagnostic but it does appear to have been broken at both ends. The fragment also appears to have a curved side and one end which is bent at almost a 90 degree angle to the main body. It may have been a small knife or cutting tool.

12/02/10 (1)

One ring of corroded iron was recovered from location 16/02/10 (3). It comprises of a flattened sheet of iron 24mm wide and 2mm thick that was rolled and then presumably welded at the end to form a ring with an inner diameter of 32mm. The two ends of the sheet that complete the circle overlap. It is not certain what this piece of iron was but could have been a pipe (although the ends do not appear to have been broken). It could also have been a ring strengthening the top of a wooden handle affixed to a cutting or chopping tool.

16/02/10 (3)

A broken, heavily corroded artefact which may have been a pair of pliers was recovered from 24/02/10 (3). Its remaining size is 166mm in length, 27mm in width and 9mm in thickness. It consists of a flattened piece of metal which tapers in width at one end and has a small perforation at the thicker end.

24/02/10 (3)

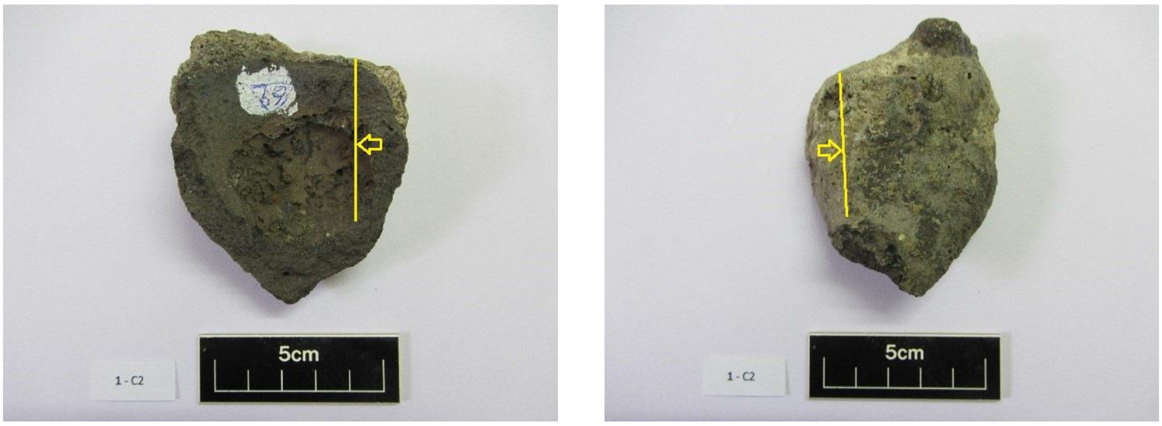
Another corroded iron ring or band was recovered from location 25/02/10 (1). Half of the ring remains but it has very similar dimensions to the one found in location 16/02/10 (3). The iron sheet is 20mm wide and up to 3mm thick forming a ring 22mm in internal diameter. Once again its purpose is unknown.

25/02/10 (1)

Appendix D – Scientific Analysis of the Assemblage

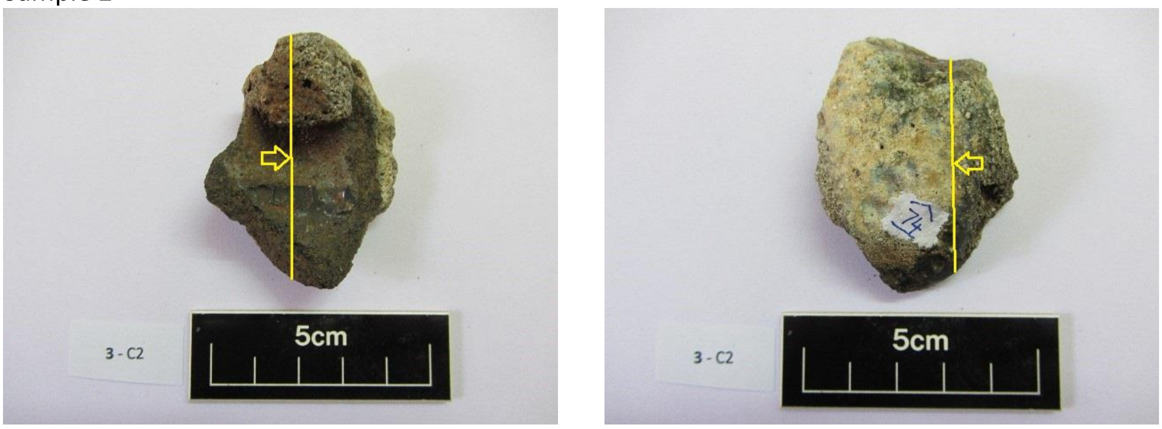
Appendix D.1 – Sample Cuts

This appendix shows the sample cuts for each material fragment analysed as outlined in chapter 4.



Sample 1

Sample 2



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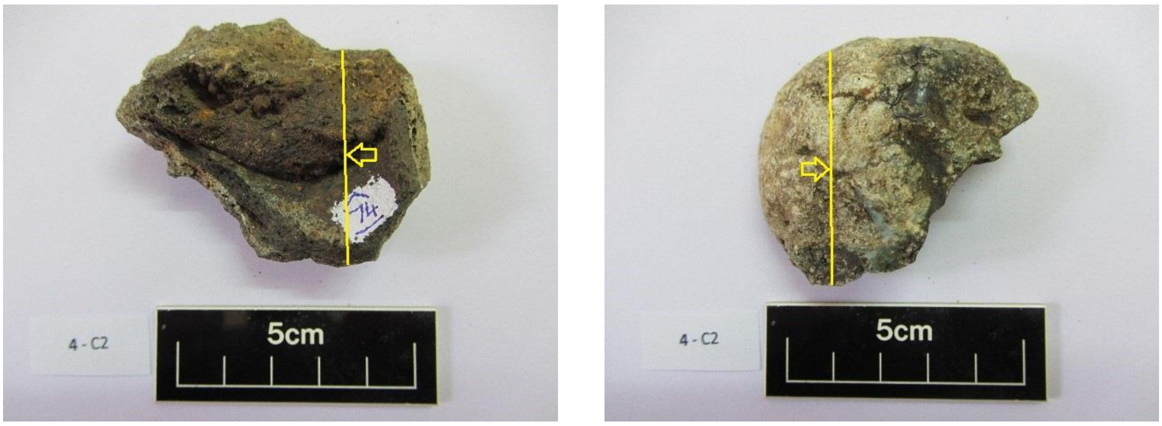
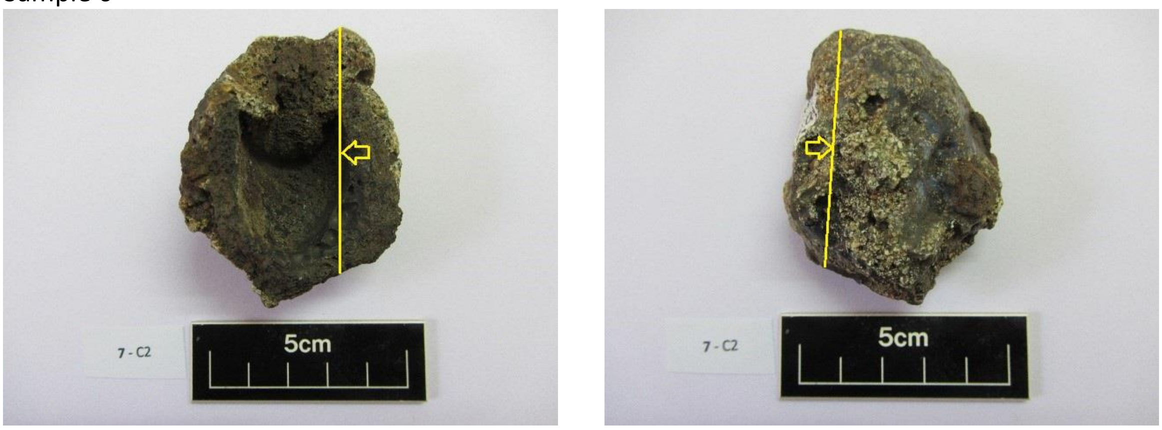


Sample 4

Sample 5

Sample 6



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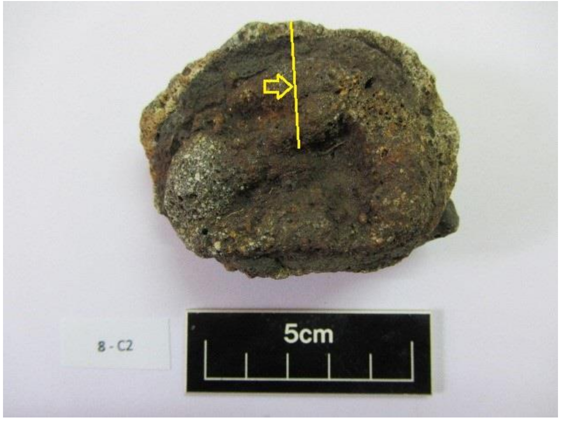

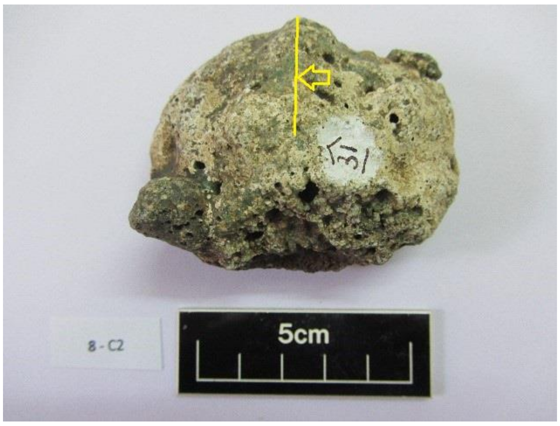

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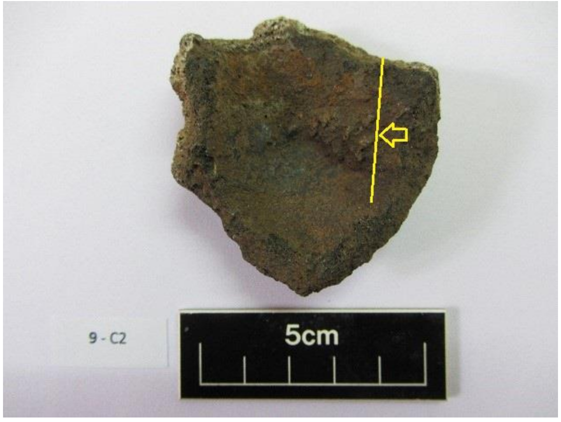

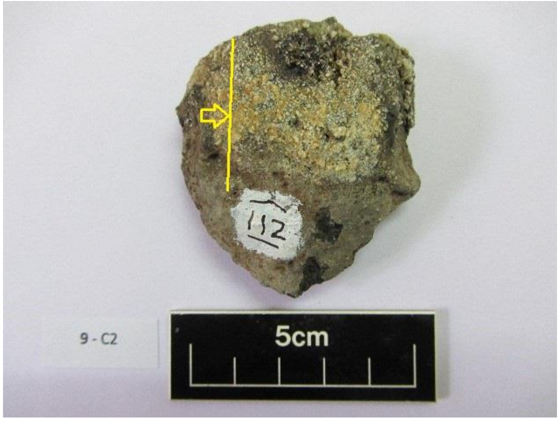

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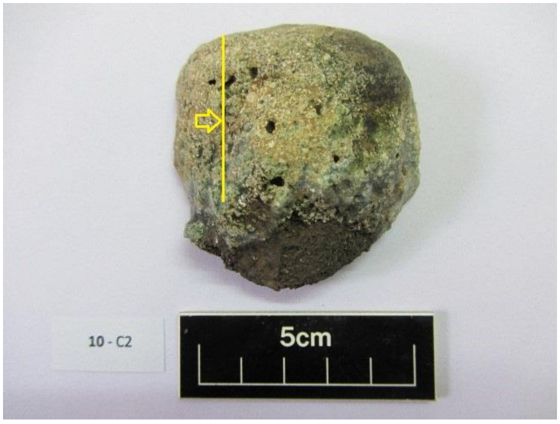

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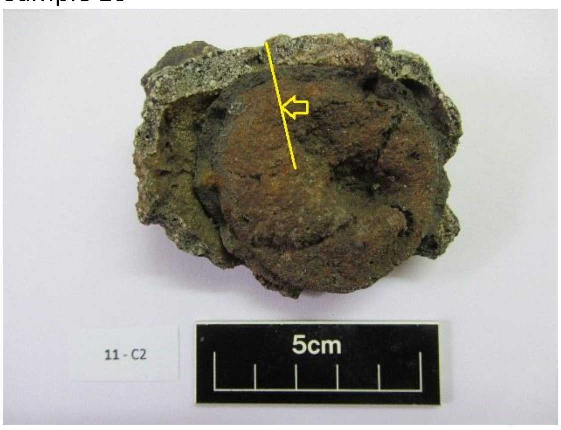
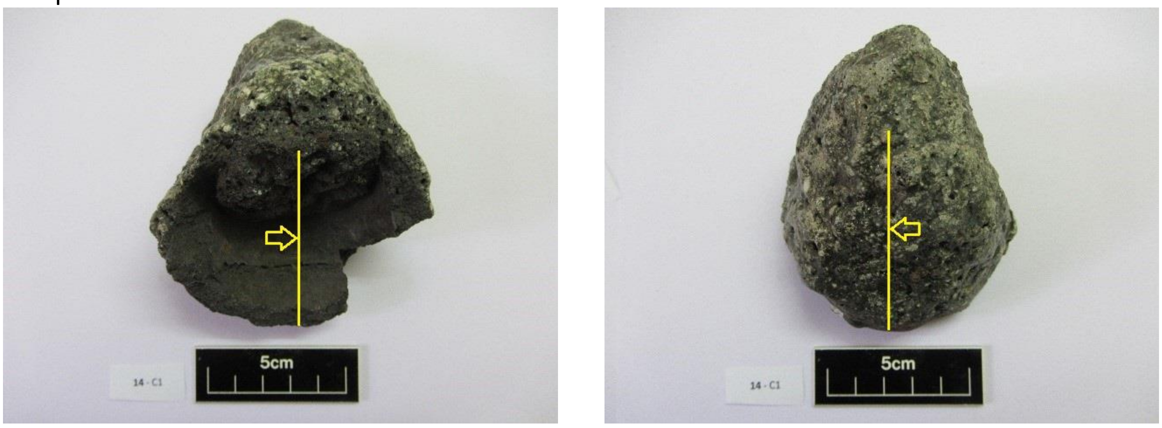


Sample 11

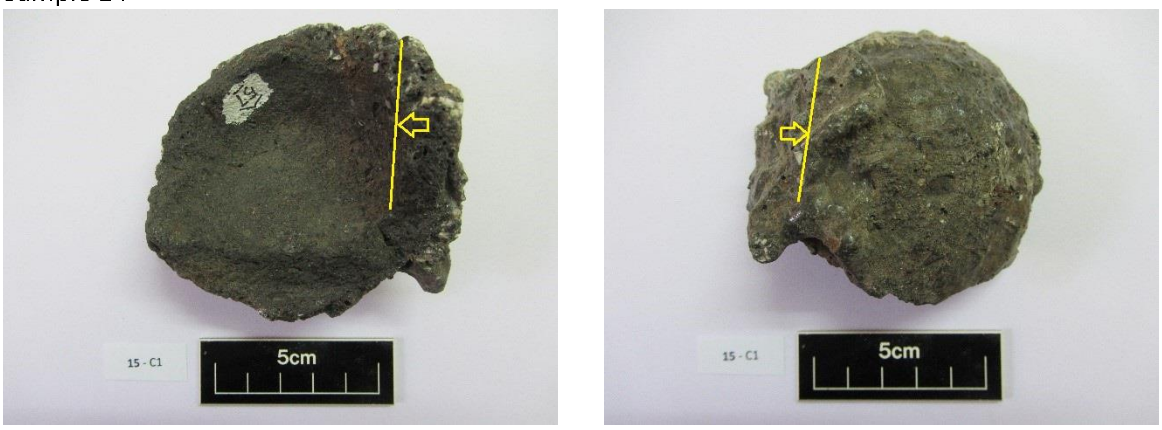
B. Girbal

Sample 12

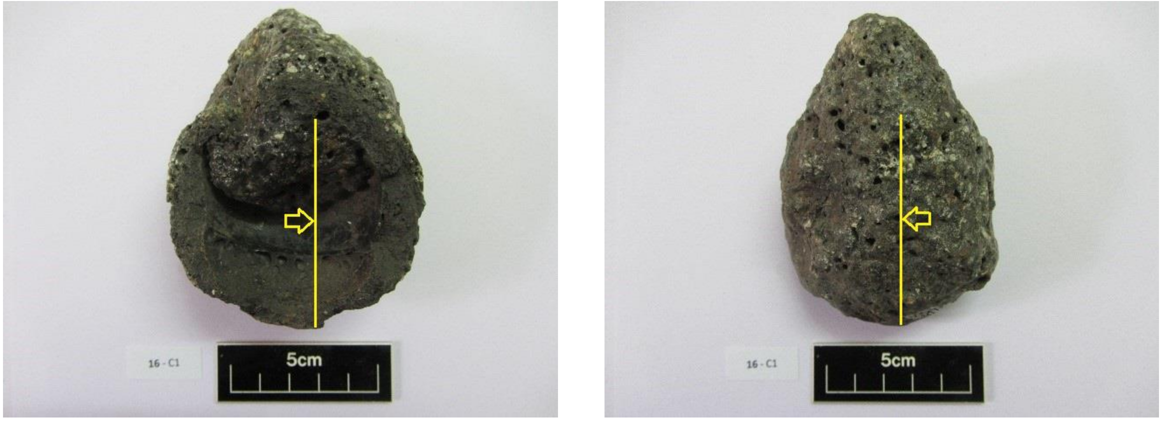
Sample 13



Sample 14



Sample 15

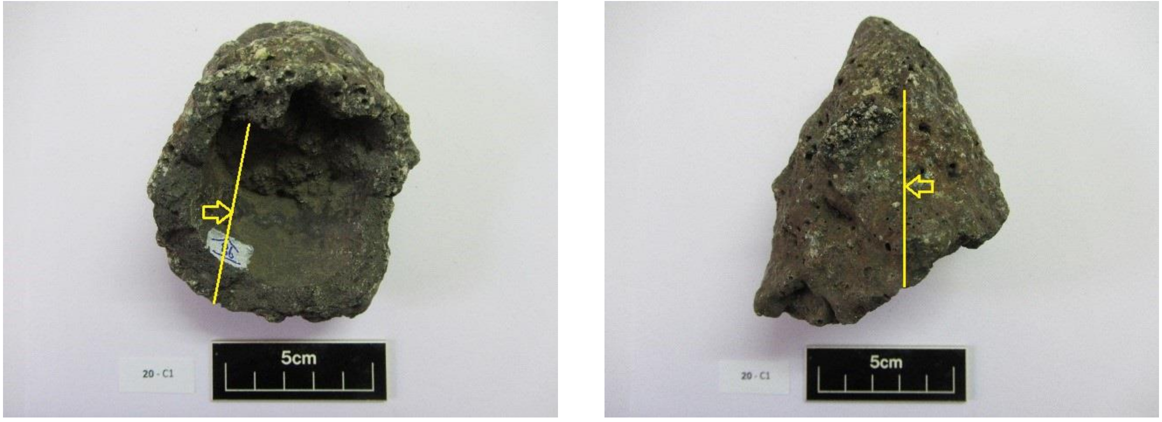


Sample 16

Sample 17

Sample 18

Sample 19



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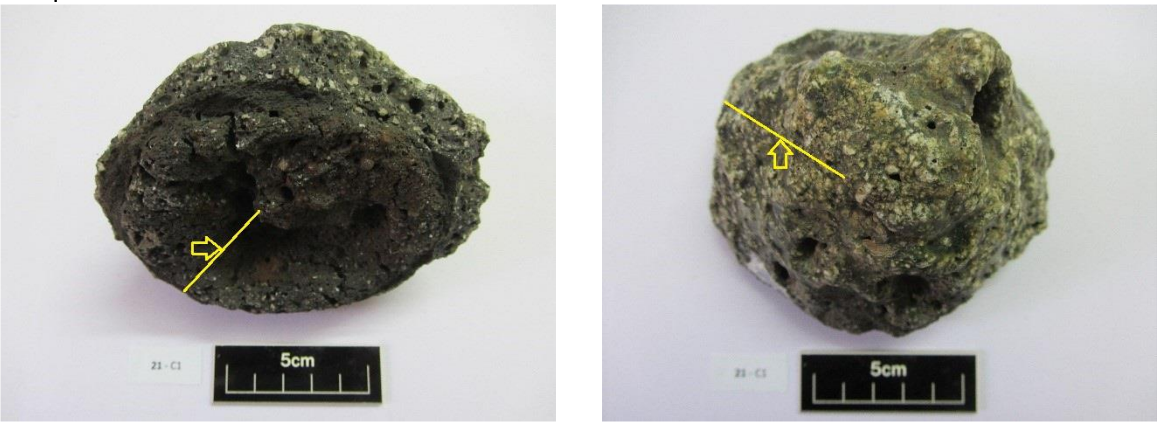

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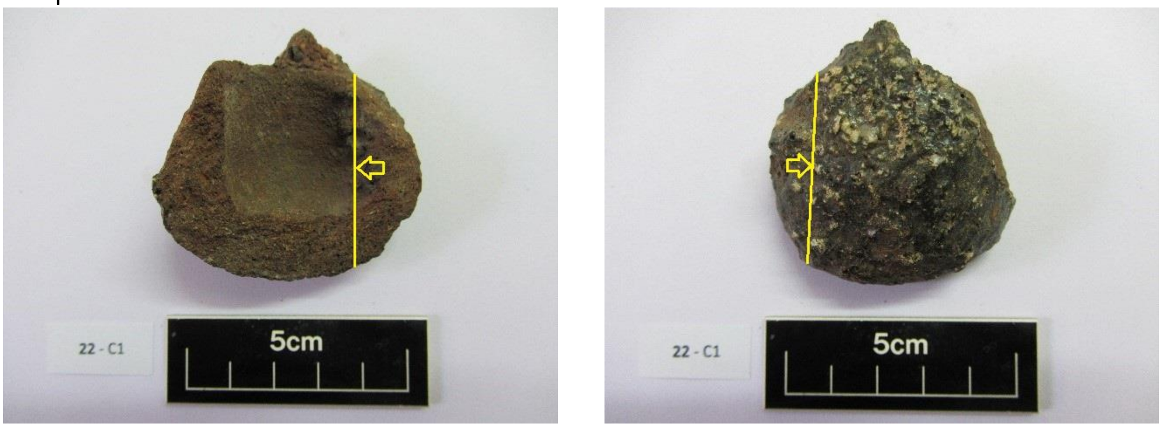
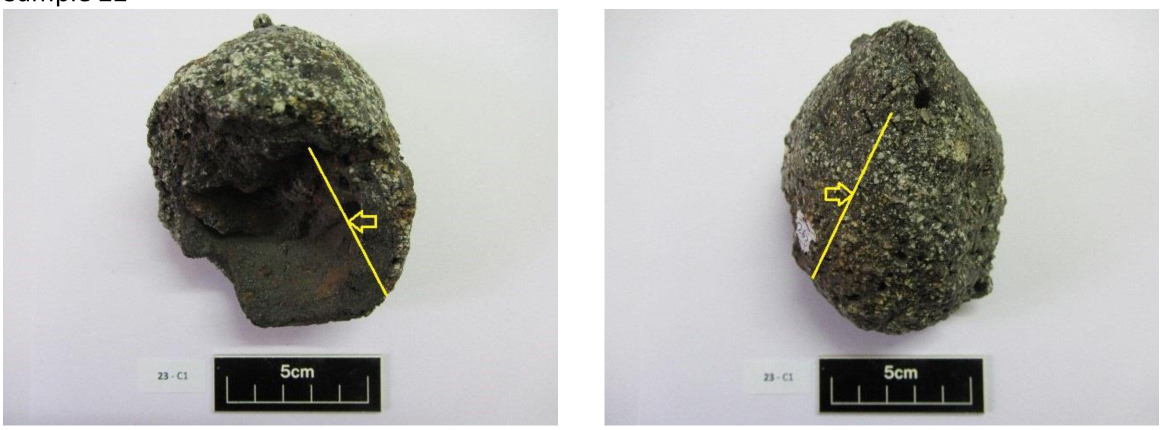


Sample 22

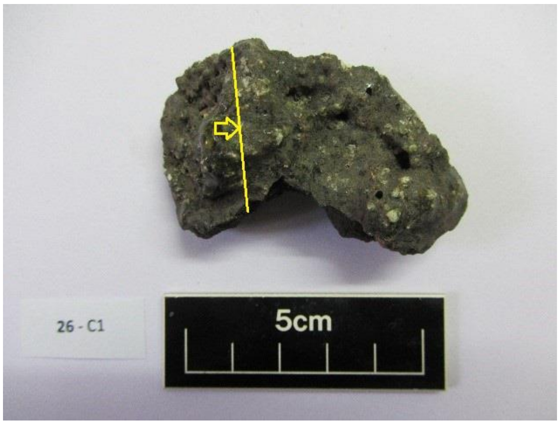


Sample 23

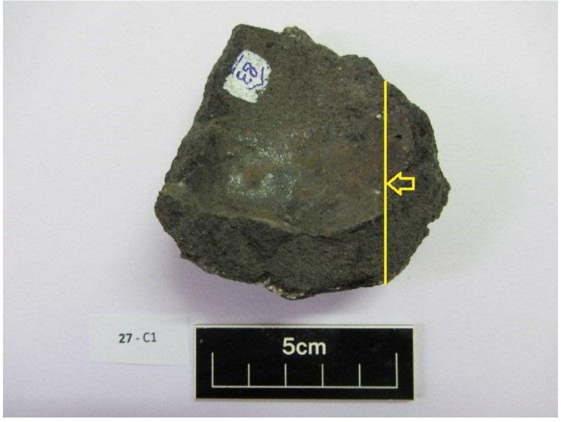
B. Girbal

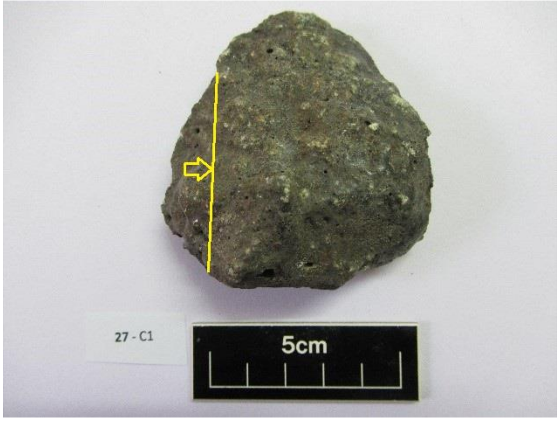
Sample 24

Sample 25



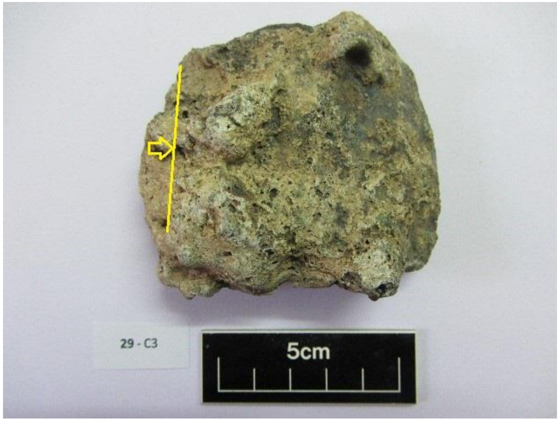
Sample 26



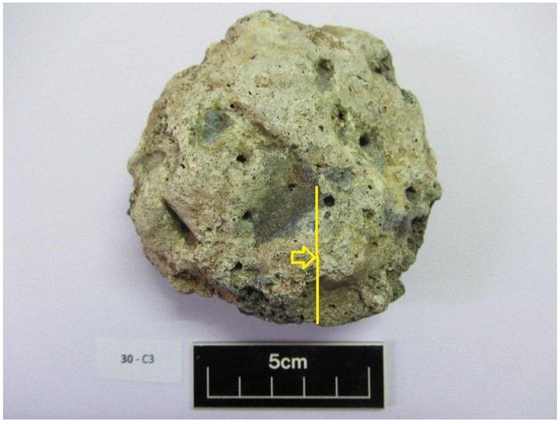


Sample 27

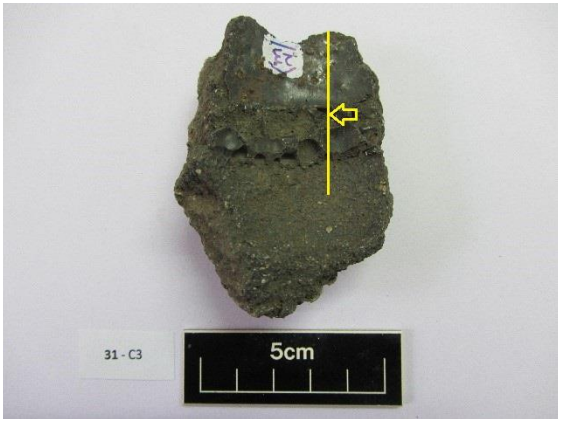
Sample 28

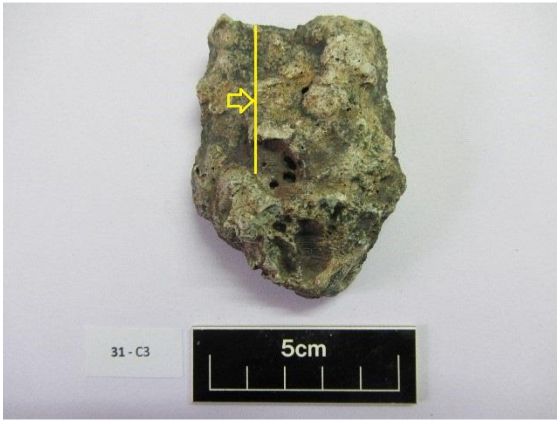


Sample 29

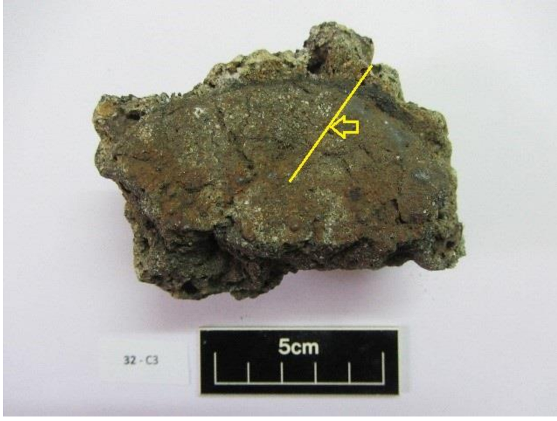


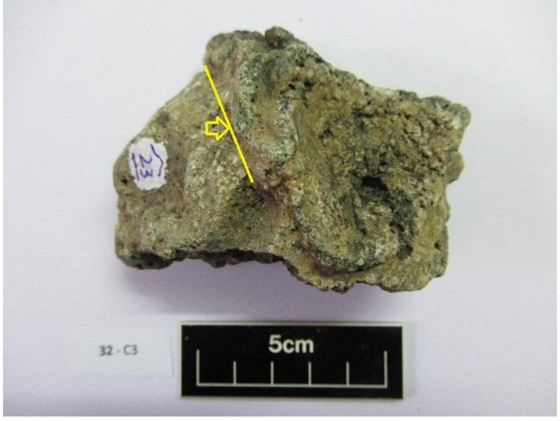
Sample 30





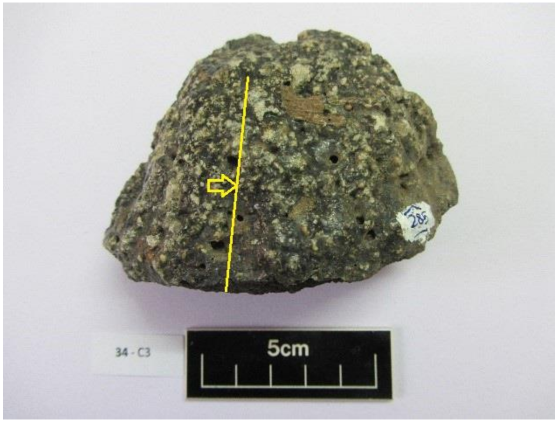
Sample 31





Sample 32

Sample 33



Sample 34

Sample 35

B. Girbal

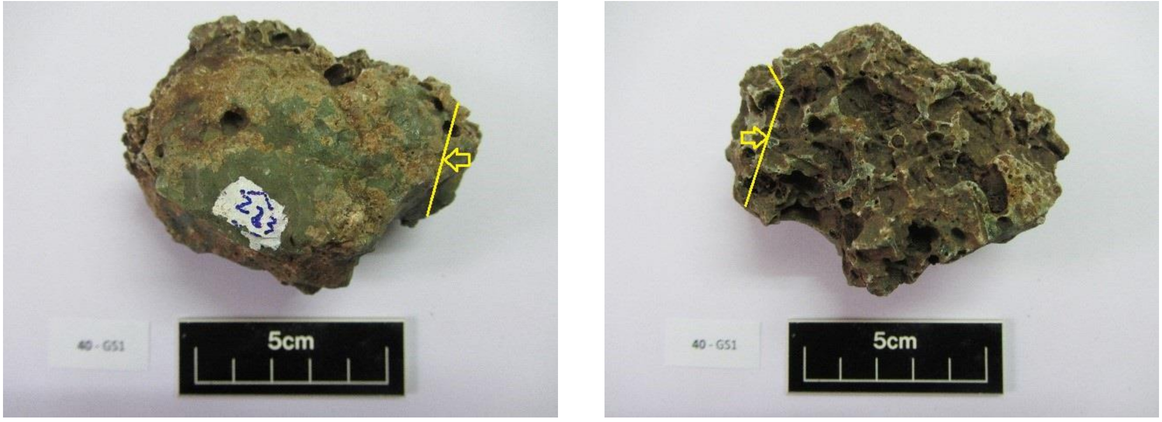
Sample 36

Sample 37

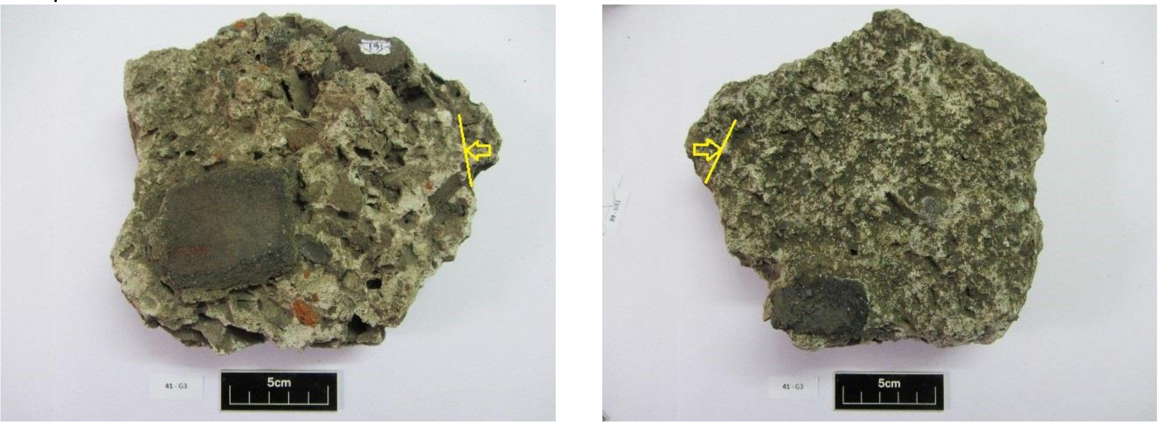
Sample 38

Sample 39

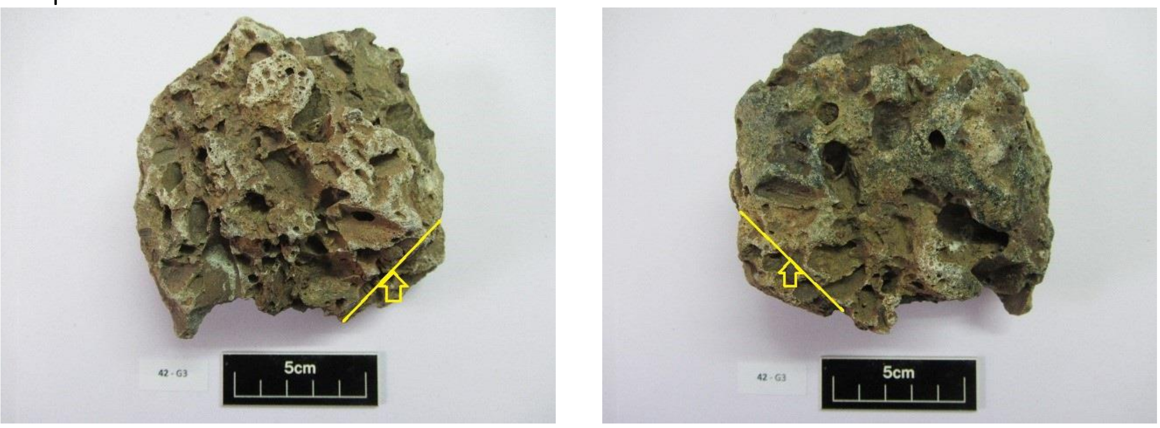
B. Girbal



Sample 40



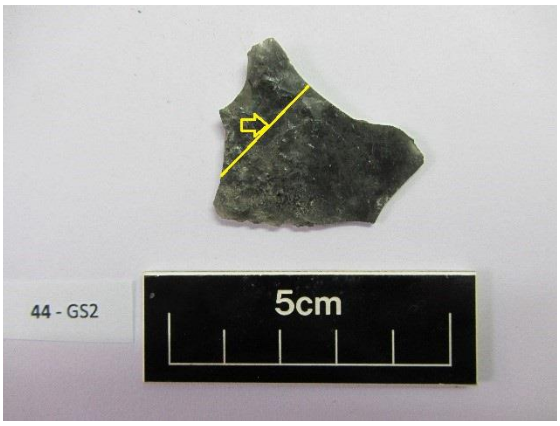
Sample 41



Sample 42

Sample 43

B. Girbal



Sample 44

Sample 45

Appendix D.2 – Sample Microstructures

Appendix D.2.1 – Crucible External Coarse Layer Fabric

This appendix summarises the microstructural observations of the coarse exterior layers of each sample analysed as outlined in chapter 4.

Spl.	**Exterior Coarse Layer**			
	Quartz	**Glass matrix**	**Voids**	**Special Features**
1	most <550m up to 1.7mm	iron prills most <8m up to 120m	some globular most <1mm and spherical most <300m	iron wash in some parts
2	most <700m up to 4.1mm	iron prills most <8m up to 115m	few spherical voids most <200 but some up to 1mm	light phase around some quartz
3	most <500m up to 1.2mm	very few iron prills up to 30m	some spherical and globular voids most <500m	
4	most <400m up to 1.5mm	very few iron prills up to 40m, most <5m	some spherical <300m and some larger globular mostly <700m	more glassy and smaller quartz close ext edge
5	most <450m up to 2mm	no to very few iron prills <5m - homogenous but some lighter areas	some spherical voids most <250m - some globular several mm in size	glassier close to ext edge
6	most <350m up to 1mm	some/few iron prills most <5m up to 75m	some spherical most <300m	
7	most <400m up to 1.8mm	some/few iron prills <5m	spherical and globular most <500m up to 1mm	
9	most <500m up to 2mm	no to very very few iron prills <10m	some spherical most <250m up to 550m	
10	most <250m up to 600m	very few iron prills most <5m	spherical most <500m up to 800m	
12	most <500m up to 700m	homogenous	some spherical most <400	glassier close to ext edge and more quartz close to main body
13	most <600m up to 1.5mm	no/very few iron prills most <5m up to 80m	spherical and globular most <600m up to sev mm	some lighter shades of matrix
14	most <500m up to 2mm	some iron prills most <10m up to 80m	many spherical voids most <400m but many globular ones sev mm	glassier close to ext edge

Spl.	Exterior Coarse Layer			
	Quartz	**Glass matrix**	**Voids**	**Special Features**
15	most <700m up to 2.7mm	many iron prills most <10m up to 40m	some spherical porosity most <500m	some change in shades of matrix
16	up to 1.8mm	many iron prills most <10m	spherical voids most <800m but some sev mm	glassier close to ext edge
17	most <600 up to 1.8mm	many iron prills most <10m up to 100m	spherical voids most <1mm but some sev mm	glassier close to ext edge - matrix shade variation
18	most <550m up to 2.2mm	many iron prills most <10m	spherical and globular voids most <700m up to 3mm	some iron wash around voids
19	none			
20	most <550m up to 2mm	many iron prills most <10m	some spherical most <500m	glassier close to ext edge
22	most <650m up to 1.2mm	very few iron prills most <5m	spherical and globular most <500m up to 1mm	
23	most <650m up to 1.8mm	many iron prills <5m up to 100m - change in shades - some tiny needle crystals (mullite?)	some spherical and globular most <400m up to 1mm	large glassy areas and glassier close to ext edge - large iron oxide wash up to 500m wide
24	most <550m up to 3.1mm	few iron prills most <5m	some spherical voids most <500m	mostly glassy with few quartz
26	most <800m up to 2mm	iron prills most <5 up to 120m - change in shades	some spherical up to 1.6mm	large glassy areas
27	most <350m up to 1mm	some/few iron prills most <5m up to 130m - some change in shades	spherical and globular most <400m up to sev mm	
29	most <500m up to 900m - some breaking up and recrystallising esp on ext edge	very very few iron prills in areas most <5m - some large laths up to 1mm long and 60m wide close to ext edge	some spherical mostly <400m	laths
31	most <450m up to 1.8mm	no small prills - very very few up to 50m	some spherical most <500 up to 1mm	
33	most <300m up to 900m	many iron prills most <10m	many spherical globular voids most <1mm - some sev mm	some FeO wash in voids - very few concentrations tiny needles (mullite?)

Appendix D.2.2 – Crucible Main Body Fabric

This appendix summarises the microstructural observations of the crucible main body fabrics of each sample analysed as outlined in chapter 4.

Spl.	**Main body fabrics**		
	Glassy matrix	**Voids**	**Special Features**
1	Iron Prills most <7m up to 50m - Silica grains - tiny needles (mullite)	normal porosity	iron wash on inner edge
2	iron prills most <5m up to 30m - silica grains - tiny needles (mullite)	normal porosity	bright areas/wash in some voids
3	iron prills most <8m - silica grains - tiny needles (mullite)	normal porosity	iron wash in some voids
4	iron prills most <5m up to 70m - small silica grains - tiny needles (mullite)	normal porosity	iron wash on int edge and around some voids
5	iron prills most <10m up to 60m - small silica grains - tiny needles (mullite)	normal porosity	some iron wash around some voids
6	iron prills most <5m - small dark silica grains - tiny needles (mullite)	normal porosity	
7	iron prills most <5m - small dark silica grains - tiny needles (mullite)	normal porosity	some iron oxide wash in some voids
9	iron prills most <5m - small dark silica grains - tiny needles (mullite)	normal porosity	some iron oxide wash in some voids
10	iron prills most <8m up to 50m - small dark silica grains - tiny needles (mullite)	normal porosity	some iron oxide wash on int edge
12	iron prills most <6m up to 40m - small dark silica grains - tiny needles (mullite)	normal porosity	iron oxide wash around some voids
13	iron prills most <5m - small dark silica grains - tiny needles (mullite)	normal porosity	some iron oxide wash around some voids and a bit on int edge with a few prills <100m
14	iron prills most <7m - small dark silica grains - tiny needles (mullite)	normal porosity	
15	iron prills most <5m up to 50m - small dark silica grains - tiny needles (mullite)	normal porosity	some iron oxide wash in some voids
16	iron prills most <10m up to 90m - small dark silica grains -	normal porosity	

Spl.	Main body fabrics		
	Glassy matrix	**Voids**	**Special Features**
	few quartz crystals up to 1mm - tiny needles (mullite)		
17	iron prills most <5m - small dark silica grains - some small quartz - tiny needles (mullite)	normal porosity	
18	iron prills most <5m - small dark silica grains - some quartz <600m - tiny needles (mullite)	normal porosity	
19	heterogeneous - crystallised - very very few iron prills most <10m up to 100m - few quartz and feldspar <40m and fine mullite needles	normal porosity	few quartz up to 500m and feldspar up to 300m
20	iron prills most <5m - small dark silica grains - some quartz <600m - tiny needles (mullite)	normal porosity	some iron oxide wash in some voids
22	some iron prills most <5m up to 80m - few quartz crystals up to 500m - small silica grains	normal porosity	some iron oxide wash on int edge up to 1mm thick
23	iron prills most <5m up to 50m - small dark silica grains - tiny needles (mullite) - some diff shades	area at top of wall much less porous + more molten /messy micro-structure - husks more complete	some iron oxide wash in some voids
24	iron prills most <7m - dark silica grains - tiny needles (mullite)	porous	
26	iron prills most <5m - small dark silica grains - 1 large quartz in centre - tiny needles (mullite)	porous	some iron oxide wash in some voids
27	iron prills most <5m up to 70m - small silica grains - tiny needles (mullite)	porous	
29	iron prills most <5m - small dark silica grains - tiny needles (mullite) - few larger quartz crystals mostly <500m	porous	some iron oxide wash in some voids
31	iron prills most <5m - small dark silica grains - tiny needles (mullite) - few larger quartz crystals mostly up to 1.2mm	normal porosity	
33	iron prills most <10m- small dark silica grains - tiny needles (mullite) - some quartz grains most <500m	normal porosity	some iron wash around some voids

Appendix D.2.3 – Crucible Lid/Cover Fabric

This appendix summarises the microstructural observations of the crucible lid fabrics of each sample analysed as outlined in chapter 4.

Spl.	Lid fabrics			
	Quartz	**Glassy matrix**	**Voids**	**Special Features**
1	None			
2	mostly <450m up to 2mm - broken up and recrystallised on int edge	few iron prills most < 5m - some microphase separation on int edge	large spherical and globular voids most <1mm up to 2mm	lots of large iron prills 150-800m and one large 3.9mm on int edge
3	most <600m	many iron prills most <5m up to 150m	spherical and globular voids up to 1mm	iron wash in some voids and on int edge
4	up to 2.4mm - some broken and recrystallised on edges	very few tiny iron prills - some microphase separation on ext edge	some spherical most <300m and some globular/broken up to 800m as well as longer elongated ones (sev mm)	iron wash rich in Si and prills embedded in pores and cracks on int edge
5	None			
6	up to 1mm	iron prills most <5m	some spherical and globular mostly <500m - some larger broken edged up to 1.7mm	less glassy matrix and more quartz - iron wash in some voids and on int edge
7	None			
9	None			
10	up to 1mm	some iron prills most <5m up to 30m	more porous than ext layer - spherical voids most <300m and large irregular voids up to couple mm	less homogenous than ext layer - iron wash on int edge with larger prills and embedded in cracks
12	None			
13	most <500m up to 800m - lots more in centre	iron prills most <1m	many globular voids most <1mm up to sev mm irregular	iron oxide wash on int edge and in cracks
14	None			
15	None			
16	None			
17	None			
18	None			
19	None			
20	None			

Spl.	Lid fabrics			
	Quartz	**Glassy matrix**	**Voids**	**Special Features**
22	None			
23	lots up to 2mm	many tiny prills most <5m but up to 300m close to int edge - in some areas lots of tiny needle crystals (mullite?) - some iron oxide wash	many globular and spherical most <1mm - some rice husks also used as temper?	iron impregnation and wash close to int edge - huge iron prill 11mm long (7mm actual + corrosion) - some laths and dark angular crystals in prill
24	None			
26	None			
27	None			
29	None			
31	None			
33	None			

Appendix D.2.4 – Crucible Internal Glassy Slag

This appendix summarises the microstructural observations of the crucible internal glassy slags of each sample analysed as outlined in chapter 4.

Spl.	Glassy Slag			
	Glass	**Thickness**	**Voids**	**Special features**
1	tiny prills most <10m	most <450m up to 1.8mm	some spherical voids up to 400m	
2	None			
3	tiny iron prills most <5m up to 70m - very few small dark silica grains <100m	up to 950m	solid	
4	none - thin layer of iron wash			
5	iron prills most <5m up to 52m - some large quartz up to 800m most <420m	most <400m but fin up to 2.5mm	some spherical voids most <200m	lots of quartz in fin but none in thin parts
6	iron prills most <6m up to 460m	up to 700m	some spherical most <150m	iron oxide wash on int edge
7	iron prills most <5m up to 70m	up to 1.5mm	very few spherical <300m	
9	iron prills most <5m up to 400m - some quartz up to 1.3mm most <550m	up to 2.3mm	few spherical most <100m	some iron oxide wash on int edge and in some voids
10	iron prills most <10m up to 250m	up to 500m	solid	
12	iron prills most <10m up to 400m (2 prills) - some quartz most <250m on intermediate zone with main body	fin up to 5mm	few spherical most <400m	some iron oxide wash on int edge
13	none			
14	iron prills most <5m up to 110m - elongated lath phase dominates	up to 1.6mm	mostly solid but many tiny spherical voids (<10m) in places	some iron wash on int edge on fin
15	iron prills most <6m up to 100m - some areas with dark angular crystals and elongated laths	most <500m	very few globular and spherical voids up to 300m	is it glass or vitrified body?
16	iron prills most <7m up to 100m - very few quartz crystals most <250m	most around 650m up to 3.3mm fin	few spherical most <300m - one sev mm	
17	iron prills most <7m up to 100m	most <700m up to 4.5mm fin	some spherical most <1mm	

Spl.	Glassy Slag			
	Glass	**Thickness**	**Voids**	**Special features**
18	few iron prills most <5m up to 50m - one large prill 200m - dominated elongated laths up to 1mm long and 50m thick - dark angular crystals <40m	most <400m up to 3.9mm fin		
19	none			
20	iron prills most <5m up to 60m	most <100m up to 1mm	mostly solid - very very few spherical voids <100m	potential charcoal 1mm in between glass and main body
22	some iron prills most <5m up to 40m - dominated elongated laths - small dark angular crystals most <30m	up to 800m	solid - very few spherical voids <250 - some <10m	is it edge vitrification? Some iron oxide wash in voids and int edge
23	iron prills most <5m up to 50m - dom by large laths (criss/cross) and maybe some small dark crystals	up to 600m	some spherical voids up to 500m	
24	iron prills most <5m up to 200m (in fin) - 1 large quartz 800m	up to 7mm fin	solid - few spherical most <100m	
26	iron prills most <5m up to 75m	most <800m up to 3.3mm fin	solid - very few spherical most <200m	
27	none			
29	iron prills most <10m up to 100m - laths and dark angular grains	most <350m up to 2.9mm	solid - very few spherical most <100m	
31	iron prills mostly <5m up to 150m	approx 1.7mm	solid - very very few spehrical most <100m	
33	iron prills most <10m - darker weird phase - very small angular grains?	approx <250m	solid	is it glass or vitrified body?